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CMP 3:45 pm–5:30 pm

Room: 314/315

Ultra Broadband Gereration and Measurements

TBA, *Presider*

CMP1 **3:45 pm**

Direct Temporal Intensity Measurement of Ultrashort Optical Pulses Using Third-Harmonic-Generation based Triple Correlation

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Because electronic devices (streak camera etc.) are too slow to measure temporal evolution of ultrashort optical pulses, many techniques were developed to retrieve 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]) All of these techniques rely on either interference or various nonlinear effect including second harmonic generation and optical Kerr effect. However, in the later 1960 it was shown that a triple correlation is sufficient to determine the temporal intensity of a laser pulse[3] with a direct mathematical calculation. In this report, we demonstrate direct temporal intensity measurement of ultrashort optical pulses using a novel third-harmonic-generation (THG) based triple correlation method. Using THG process in a single GaN thin film, the optical pulse intensity profile from a mode-locked Cr:forsterite laser was directly obtained with the background free triple correlation trace without any spectral information and pulse-shape assumption. This is different from the previous demonstration[4] where triple correlation was obtained through a complex combination of second-harmonic generation and sum-frequency-generation. In order to retrieve the corresponding phase information, a simple genetic algorithm was also developed for the first time based on the direct optical spectrum measurement with improved O(n) complexity than O(n²) in.[1]

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

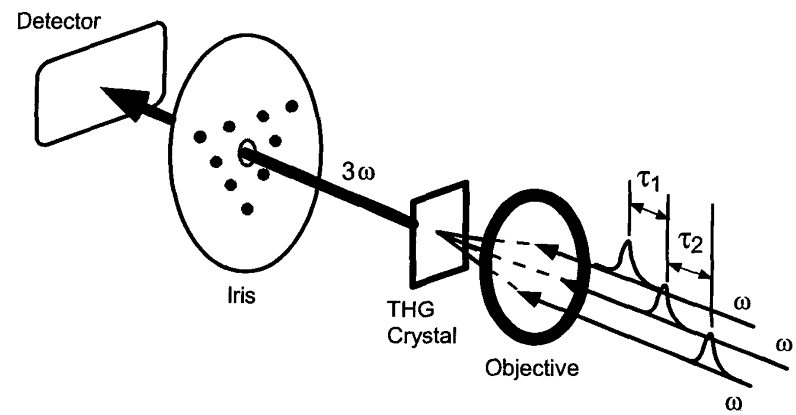
$$I(t) = \int \tilde{I}(\nu)\exp(-i2\pi\nu t)d\nu = \int |\tilde{I}(\nu)|\exp(i\alpha(\nu) - i2\pi\nu t)d\nu \quad (1)$$

where $|\tilde{I}(\nu)|$ and $\alpha(\nu)$ 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 and THG signal with three fundamental frequency photon contributed from three individual pulses was spatially selected with an iris according to momentum conservation law as shown in Fig. 1. By varying the time delay between pulses τ_1 and τ_2 and recording the selected THG signals with a detector, the background-free triple correlation

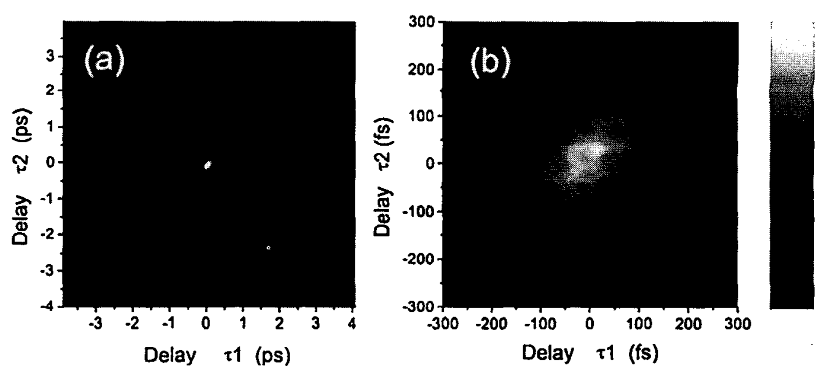
$$G^3(\tau_1,\tau_2) = \int I(t)I(t+\tau_1)I(t+\tau_2)dt \quad (2)$$

was directly measured. Then we can use bispectrum $\tilde{G}^3(\nu_1,\nu_2)$, the Fourier transform of triple correlation function, to calculate $|\tilde{I}(\nu)|$ and $\alpha(\nu)$,[3] and thus determine the I(t) using equation (1).

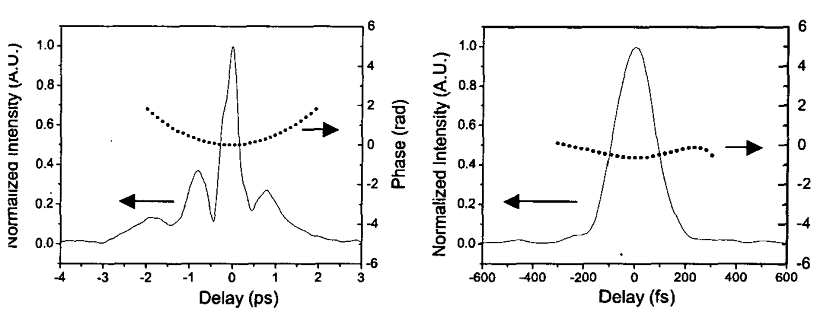
Figure 2 shows two examples of the obtained triple correlation traces of ultrashort laser pulses



CMP1 **Fig. 1.** Diagrammatic representation of THG based triple correlation.



CMP1 **Fig. 2.** Two THG triple correlation traces of optical pulses from a modelocked Cr:forsterite laser.



CMP1 **Fig. 3.** Recovered temporal intensity and phase profile corresponding to the THG triple correlation traces in Fig. 2.

from a modelocked Cr:forsterite laser using a GaN thin film as the THG crystal. The laser wavelength was centered around 1230 nm. In order to distinguish the THG signals from other photoluminescence signals through multi-photon absorption, we use a CCD based spectrometer as the detector. In one of the measurement, we distorted out laser pulseshape intentionally by misarranging the laser cavity (Fig. 2(a)). Diagonally symmetric traces were obtained, which is the characteristic of triple correlation. Their corresponding recovered temporal intensity are calculated and shown in Figure 3(a) and (b) respectively (solid line), whose mathematical autocorrelations agree with the measured one based on a SHG autocorrelator.

In order to retrieve the corresponding phase information, a simple genetic algorithm was also developed for the first time based on the direct obtained optical pulse temporal intensity profile as shown in Figure 3 with the aid of a direct optical spectrum measurement (not shown here). This simple algorithm has improved O(n) complexity compared with most other iterative algorithm with $O(n^2)$ complexity.[1] Thus retrieved temporal phase is also shown in Figure 3 (dotted line).

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CMP2 **4:00 pm**

Novel adaptive scheme for acousto-optic gain equalization and ultrabroadband amplification

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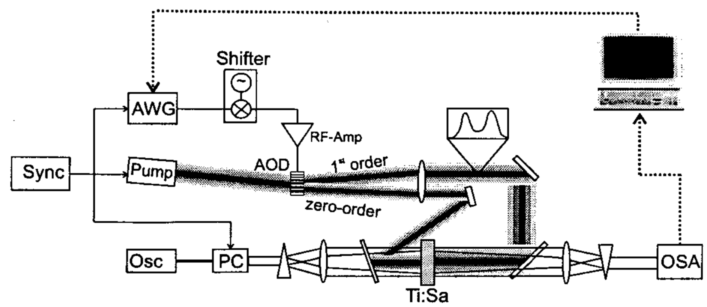
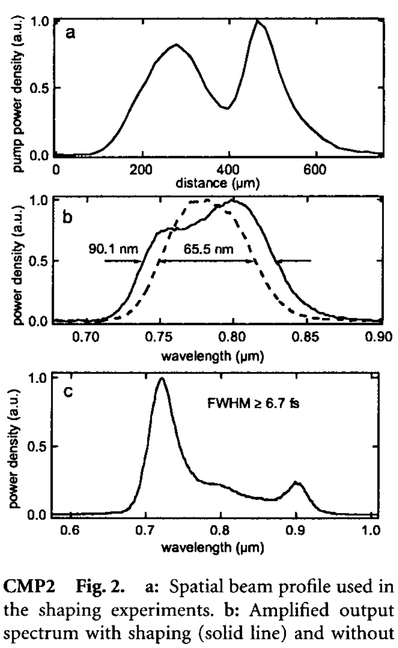
Adaptive control is an extremely powerful tool for optical pulse shaping.[1] For amplifier systems, e.g., phase shaping was employed for compression of ultrashort pulses[2] and optimized high-harmonic generation.[3] In this paper, we will introduce a method for amplitude shaping that allows for an adaptive spectral redistribution of amplifier gain. Rather than previous attempts to overcome the detrimental gain narrowing effect (e.g., the use of antiresonant etalons[4]) our method does not introduce a spectrally dependent loss. Our alternative approach uses gain shaping by generation of a suitable spatial pump profile. In contrast to previous demonstrations,[5,6] our concept can be used adaptively to produce a particular spectral profile of the amplified pulse and is based on acousto-optic imaging of the pump laser.

Our setup is depicted in Fig. 1. The pump source is a Q-switched Nd:YLF laser operating at 523.5 nm, producing 6-mJ pulses at a repetition rate of 1 kHz. The pulses from this laser are fed into an acousto-optic deflector (AOD) with a center frequency of 100 MHz and a bandwidth (3dB) of 50 MHz, operating at efficiencies of <70% by deflection into the first order. We use an arbitrary waveform generator and an rf amplifier to write an arbitrary acousto-optic grating into the AOD. With the first-order Bragg angle being a function of grating period, control of the frequency distribution of the driver wave allows to generate a desired image of the pump beam. One example of a generated spatial beam profile is shown in Fig. 2a. This distribution has been generated by applying two consecutive sinusoidal functions linearly chirped in frequency. The deflected and the non-deflected beams are used to pump a 1-cm long Ti:sapphire crystal from two opposing sides. The 6-pass amplifier is seeded with pulses from a sub-10-fs Ti:sapphire laser (see Fig. 2c). The spatial dispersion of the different frequency components of the pulses is produced by a 4*f*-system consisting of 10-degree silica prisms and *f* = 375 mm lenses.



CMP2 Fig. 1. Schematic setup of the acousto-optic gain shaper. Note that only one pass is shown for simplicity. AWG: arbitrary waveform generator. Shifter: frequency-shifter to convert AWG output into the 100-MHz range, RF-Amp: radio-frequency power amplifier, AOD: acousto-optic deflector, Osc: Kerr-lens modelocked Ti:sapphire laser producing sub-10-fs pulses, PC: Pockels cell used as pulse picker, Pump: Nd:YLF laser, producing 6 mJ pulse energy at 1 kHz repetition rate, Ti:Sa: 1-cm Ti:sapphire crystal, OSA: optical spectrum analyzer.



CMP2 Fig. 2. **a:** Spatial beam profile used in the shaping experiments. **b:** Amplified output spectrum with shaping (solid line) and without shaping (dashed line). **c:** Ti:sapphire oscillator spectrum used as seed.

An example for the spectral shaping capabilities of our setup is illustrated in Fig. 2b. Operating the AOD with a single-frequency rf wave at 100 MHz, i.e. disabling the shaping effect, gain narrowing reduces the spectral width of the amplified pulse to 65 nm. Enabling gain shaping with the spatial profile in Fig. 2a broadens the output spectrum to a FWHM of 90 nm, an improvement of nearly 40%. Proper dispersion compensation provided, such a spectrum directly supports a 13.5-fs pulse. So far, we reached a net gain of 4000 and output energies in the μJ-range with shaping enabled. As our technique can be adapted within a wide range of spectral shapes, it appears promising for the generation of sub-10-fs pulses directly from Ti:sapphire amplifiers. A further application may be the optimization of the pulse profile for high-harmonic generation or hollow-fiber compression.

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