High-sensitivity spectral phase retrieval of 7.2 fs pulse by shaper-assisted modified interferometric field autocorrelation

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Abstract: We report on spectral phase retrieval of 16 pJ, 7.2 fs pulse and tailored waveforms at 800 nm by shaper-assisted modified interferometric field autocorrelation. Experiment results confirm the high accuracy and reproducibility of this method.
OCIS codes: (320.7100) Ultrafast measurements; (320.7110) Ultrafast Nonlinear optics; (320.5540) Pulse shaping

1. Introduction

Few-to-single-cycle optical pulses are useful for time-resolved spectroscopy [1] and isolated attosecond pulse generation [2]. An integrated system to simultaneously measure and manipulate [3] these ultrabroadband waveforms that could overcome the profound impact of dispersion is highly desirable. A variety of pulse measurement techniques, such as SPIDER [4], FROG [5], MIIPS [6], and sonogram [7], have been realized with a built-in pulse shaper. However, they generally have low sensitivity due to the employment of thin nonlinear crystals. Previously we measured the spectral phase of 1.1 nJ, 8.1 fs pulse at 600 nm by the modified interferometric field autocorrelation (MIFA) method, where a standard Michelson interferometer (MI) and 300-μm-thick LBO crystals were used [8]. The finite spectral response of the beam splitter and the fluctuation of delay scanning of the MI restricted the performance of the method. In this work, we report substantial improvements on the accuracy, reproducibility, minimum pulse energy (16 pJ) and measurable pulse width (7.2 fs) of MIFA by including a pulse shaper and use of a 40-μm-thick BBO crystal in the measurement method.

2. Experiment

Figure 1(a) shows the setup of shaper-assisted MIFA. A Ti-sapphire oscillator (Femto Lasers, Rainbow) produced 76 MHz, sub-7 fs signal pulses at 800 nm (f_0 =375 THz). A Fourier pulse shaper consisting of gratings (200 gr/mm), concave mirrors (f =200 mm), and a spatial light modulator (CRI, SLM-128-D-VN) was utilized to generate pulse replicas with variable delay. A 40-μm-thick type-I BBO crystal was used for second-harmonic generation (SHG). The corresponding bandwidth of the phase-matching response would distort the SHG spectrum [Fig. 1(b)], causing error for all nonlinear pulse measurement techniques except for MIFA [8]. Meanwhile, the group delay dispersion (GDD) of the 40-μm BBO will broaden a 6.8 fs transform-limited (TL) pulse at 800 nm to 6.9 fs, causing only nominal measurement error. The SHG spectrum at each delay was recorded by a spectrometer (Ocean Optics, HR4000), from which one could get two MIFA traces by sampling the spectrogram at two frequencies [9,10].

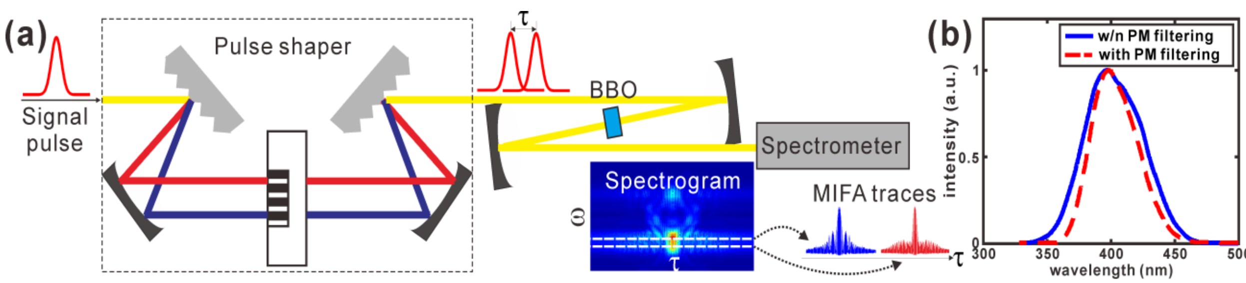

Fig. 1. (a) Experimental setup. (b) SHG power spectra of a TL pulse without (solid) and with (dashed) phase-matching (PM) filtering.

We first measured the spectral phase functions of pulses before and after passing through a 2-mm-thick SF56A glass. Fitting the spectral phase difference function around 800 nm gives a GDD of 196 fs^2, very close to that (197 fs^2) predicted by the Sellmeier equation. Figure 2 shows the spectral phase profiles of a chirped pulse retrieved by MIFA (solid) and FROG (dashed, with a FROG error of 0.006) using 40-μm- and 10-μm-thick BBO crystals, respectively. They are in good agreement over a spectral range of 130 THz. The minimum pulse energies required for MIFA and FROG were 16 pJ and 210 pJ, respectively. The chirped pulse was compressed by subtracting the measured spectral phase, and then characterized by MIFA (Fig. 3). The residual spectral phase varies within 0.6 rad over the 130 THz spectral window. The temporal intensity (Fig. 3, inset) obtained by inverse Fourier transform of the measured spectral intensity and phase has a clean shape and 7.2 fs FWHM, about 6% wider than the TL width.

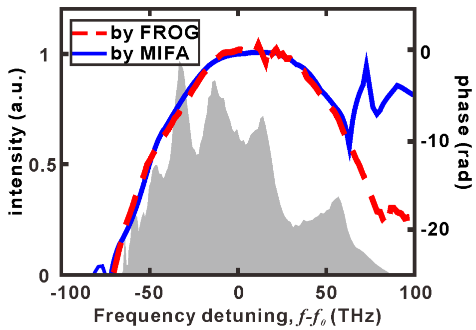

Fig. 2. Power spectrum measured by a spectrometer (shaded), and the spectral phases retrieved by FROG (dashed) and MIFA (solid), respectively.

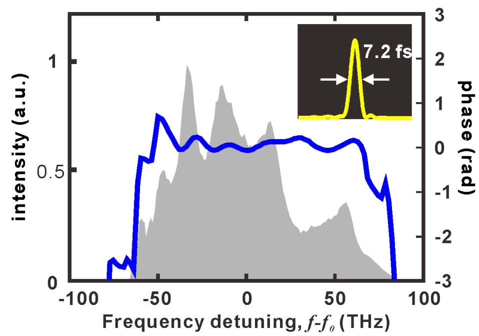

Fig. 3. Power spectrum (shaded), and the residual spectral phase retrieved by MIFA (solid). Inset: The corresponding temporal intensity.

The shaper-assisted MIFA system was also used in measuring three types of nontrivial spectral phases (sinusoidal, square, and π-phase step) added to the TL pulse by the same pulse shaper (Fig. 4, solid). The experimentally retrieved phase functions (Fig. 4, dashed) agree well with the added ones, where even the abrupt phase jumps were accurately resolved. The reproducibility of our shaper-assisted MIFA system was demonstrated by measuring a spectral phase function for 10 times. A color-coded histogram of experimentally measured spectral phases is shown in Fig. 5. The standard deviation of phases within a frequency detuning range from -50 to 50 THz is smaller than 0.57 rad.

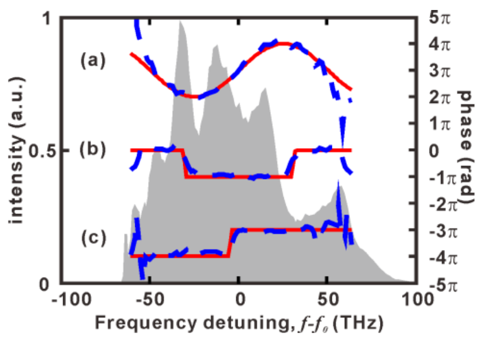

Fig. 4. Power spectrum (shaded). The three types of spectral phases added by the shaper (solid) and retrieved by MIFA (dashed), respectively.

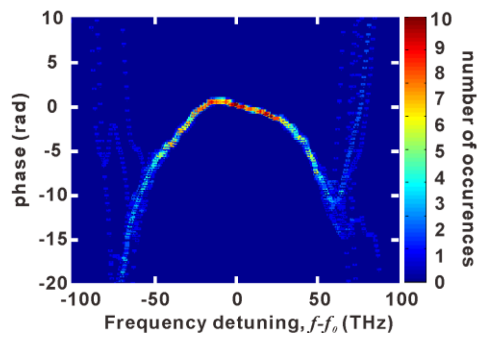

Fig. 5. Color-coded histogram of ten experimentally measured spectral phases.

3. Conclusion

We have demonstrated that the shaper-assisted MIFA method can retrieve the spectral phase of ultrashort pulses down to 7.2 fs at 800 nm with high sensitivity, accuracy, and reproducibility. Complicated waveforms with ultrafast time structure can be reliably generated and characterized in an integrated system. This work was supported by the National Science Council of Taiwan under grant NSC 100-2221-E-007-093-MY3 and by the National Tsing Hua University under grant 101N7081E1.

4. References

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