

Characterization of sub-10-fs Pulses Using Spatially Encoded Arrangement for SPIDER

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Abstract: Using a spatially encoded arrangement for SPIDER, we accurately measure ultra-broadband sub-10-fs pulses that can exhibit a modulated spectrum and space-time coupling. The intuitive interferograms can be acquired single shot and real time.

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The wide availability of robust methods for generating intense, sub-10-fs pulses has led to their use in numerous applications. Common generation methods include noncollinear optical parametric amplification (NOPA) or hollow core fiber (HCF) pulse compression [1]. In such methods, the spectrum can be highly modulated or the pulse can exhibit space-time coupling (STC). These characteristics, an ultra-broadband spectrum (e.g. over an octave) and the desirability to measure single-shot or real time, or both, makes the measurement of these pulses using conventional techniques very problematic [1].

Here we demonstrate an extremely accurate method of measuring the spectral phase of sub-10-fs pulses using a spatially encoded arrangement for spectral phase interferometry for direct electric-field reconstruction (SEA-SPIDER) [2]. Using such a technique, it is possible to measure the phase over the whole spectrum at every point across a slice in the beam. Thus it is possible to measure STC, even if the spectrum is highly modulated. It is also possible to perform single shot acquisition in real time, making this method preferential over conventional techniques for complete characterization of sub-10-fs pulses.

The SEA-SPIDER concept is shown in Fig. 1. The test pulse with unknown phase upconverts with two temporally separated, highly chirped pulses in a type II nonlinear crystal. During the upconversion, the test pulse sees two different quasi-monochromatic frequencies from the chirped pulses, resulting in two spectrally sheared replicas of the test pulse. These two signal pulses are sent into a 2D imaging spectrometer, where spatial fringes result from the wavefront tilt between the two signal pulses.

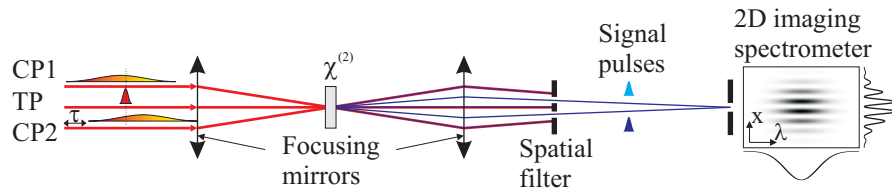


Fig. 1. (a) SEA-SPIDER concept: TP = test pulse, CP1/CP2 = chirp pulse 1/2, τ = time delay.

We measured the phase of a sub-10-fs oscillator with a spectrum covering a range of 650-1000 nm. This is enough bandwidth to support a Fourier transform limited (FTL) pulse duration of 6.5 fs full width half max (FWHM). In the absence of STC, the SEA-SPIDER interferograms provide a intuitive map of the spectral phase. The dotted lines in Fig. 2 show the contours of the fringe pattern, which directly map the group delay of the pulse. A FTL pulse has perfectly horizontal fringes, see Fig. 2 (a). Figure 2 (b) shows the effect of some small residual higher-order dispersion, e.g. a slight dispersion ripple which can arise from chirped mirrors. Figures 2 (c) and (d) show the effect of positive or negative group velocity dispersion (GVD) respectively. The sign and magnitude of the dispersion is indicated by the spectral slope of the fringes.

To test the accuracy of the method, we added known dispersion to the test pulse and compared this to the measured phase. Figure 3 (a) shows the known and measured phase for 1 cm of fused silica. The agreement is excellent, the two profiles are almost indistinguishable over the whole spectral range, even at positions of low spectral intensity (e.g. < 725 nm). The phase of the test pulse measured using a SEA-SPIDER was also compared to the phase measured with a conventional SPIDER (Fig. 3 (b)). It is clear that the two

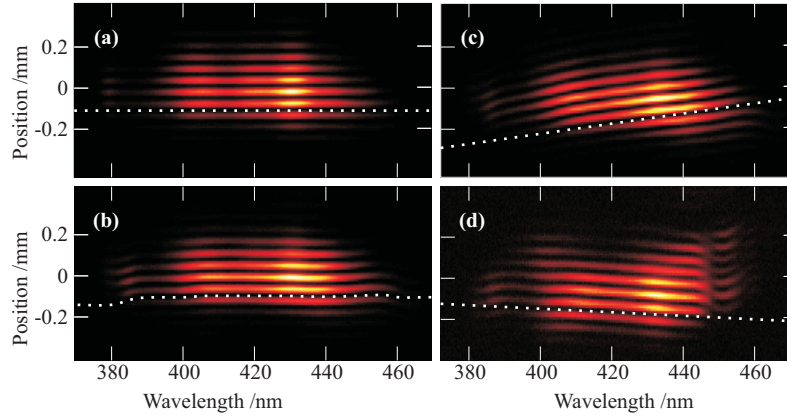


Fig. 2. SEA-SPIDER interferograms, dotted lines show fringe pattern: (a) calibration trace (i.e. zero shear); (b) SEA-SPIDER measurement of the sub-10-fs oscillator; (c) SEA-SPIDER measurement of a positively chirped pulse and (d) SEA-SPIDER measurement of a negatively chirped pulse

phases are the same over the range 725-950 nm. Below 725 nm, the SEA-SPIDER shows that the phase is highly nonlinear. Tests confirmed that this phase is physical and can be attributed to a limited bandwidth of the chirped mirrors used inside the oscillator. Due to the low spectral intensity, the SPIDER apparatus is unable to resolve spectral fringes and thus cannot measure this phase accurately. The effect of this phase error can be seen in Fig. 3 (c). Both methods give similar pulse durations of 7.9 fs (SPIDER) and 8.6 fs (SEA-SPIDER), however conventional SPIDER was unable to resolve the significant sub pulse at 15 fs which is a direct result of not being able to measure the phase accurately over the whole spectrum.

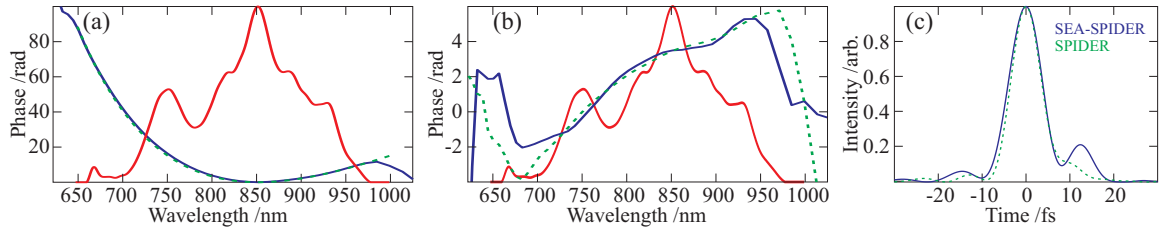


Fig. 3. Pulse reconstruction: (a) measured (blue) and calculated (green) phase of 1 cm fused silica, (b) oscillator phase reconstruction from SEA-SPIDER (blue) and SPIDER (green), and (c) temporal reconstruction from SEA-SPIDER (blue), SPIDER (green).

Sub-10-fs pulses typically have spectrum and phase which are a function of transverse position, attributed to the method of generation (e.g. NOPA or HCF). Thus in many experiments, it is critical to measure the exact pulse shape at every point in the beam. SEA-SPIDER allows complete pulse reconstruction at every point in a slice across the beam. Using the real-time capability of SEA-SPIDER, it is possible to optimally align such laser systems.

In summary, we have demonstrated SEA-SPIDER as a method of accurately measuring the complete pulse shape of sub-10-fs pulses, even in the presence of modulated spectrum, regions of low spectral intensity and/or space-time coupling. The technique was shown to accurately measure regions of spectral phase which conventional SPIDER could not, which can be critical in certain experiments.

References

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