SPIDER diagnostics technique for Vulcan 10 PW OPCPA project

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Introduction

When optimizing stretcher-compressor setups in CPA systems, one can use just an autocorrelation to find the minimal pulse duration. However, this approach is biased by many ambiguities and doesn't straightforwardly lead to the shortest achievable pulse duration. For a reliable method to optimize the system, one needs to monitor the spectral phase of the pulses at the end of the system. To provide this ability to monitor the spectral phase for the Vulcan 10PW OPCPA project, it has been decided to build a SPIDER diagnostic [1] (Spectral Phase Interferometry for Direct Electric-field Reconstruction).

Principle of operation

A short pulse entering the SPIDER is split into three components. Two of the short pulse replicas are separated in time (creating a pulse pair). They are generated by a reflection on both sides of a thin uncoated etalon or in a Michelson interferometer. The third pulse replica that contains most of the pulse energy is stretched in time in a dispersive material or grating stretcher. The stretch factor should be large enough, so the phase of the stretched pulse is considered constant over the time period equal to the duration of the original pulse.

Then the pulse pair and the stretched pulse are brought together in a frequency doubling crystal, like BBO, and the sum frequency is generated. Each pulse of the pulse pair interacts with a different frequency of the stretched pulse, so there will be a spectral shear in the upconverted light. The upconverted light is sent to a spectrometer where the spectral components of the pulses are separated and, because they behave like a monochromatic wave, interference occurs among them. The result is a spectrum modulated by a set of sinusoidal fringes.

If all frequencies in the original pulse are exactly in phase, the fringes in the spectrum will be linearly spaced. If there are any phase differences among frequencies, the fringe separation will vary across the spectrum. By recording and analyzing the fringe positions, a measurement of the spectral phase in the original pulse can be obtained.

For extracting the phase, the recorded SPIDER trace is Fourier transformed (FT) and the fringe spacing variation along the spectrum is extracted. The intrinsic spacing variation caused by a wavelength has to be subtracted. This calibration trace is obtained by blocking the stretched beam and recording only the second harmonic from the pulse pair.

Design

The SPIDER is designed to measure 10-15 fs pulses with 200 nm bandwidth centered around 900 nm. The design of SPIDER was based on the existing SPIDER device from Astra [2] which is used to measure almost the same pulse durations. However, some modifications were made based on Labview simulations using the LAB2 femtosecond package.

The etalon thickness has to be chosen according to spectrometer resolution and pulse spectrum width. The SPIDER trace should have more than 30 fringes with more than 5 points per fringe in order for the FT algorithm to work properly. The extremely broad spectrum and a high resolution (0.07 nm) commercial spectrometer (Ocean Optics HR4000, 3648px, 16-bit) allowed the use of a fused silica (FS) etalon 50-125 µm thick. The final etalon thickness was set to 100 µm producing a pulse pair with 1ps delay between pulses. This etalon provides ca. 100 fringes with 7-12 pts per fringe.

The stretched pulse duration, which should be 10-20 times the delay between the pulses in the pulse pair, was chosen to be 10-13 ps. The stretcher uses two 830 l/mm gratings which were selected for their relatively high diffraction efficiency (80%) and small dispersion. The stretcher works in a double pass configuration with an incident angle of 45° and a grating separation of 4 cm. If necessary, the grating stretcher can be replaced by 15 cm of high dispersive glass in a double pass configuration.

The BBO frequency doubling crystal was chosen for its relatively high gain and broad conversion bandwidth. The crystal thickness is 40 µm. At this thickness no severe spectrum shift and bandwidth degradation is observed. The upconversion works in Type II interaction with non-collinear incidence to reduce background created by an unwanted second harmonic frequency generation (SHG) in each of the beams.

Layout

Layout of the SPIDER is presented in figure 1. The whole setup was fitted onto a 60 × 37 cm breadboard. The vertically polarized incident beam passes through two alignment apertures. The pulse pair is reflected off the etalon and steered by flat mirrors to the f = 100 mm spherical mirror in front of the BBO crystal. The main pulse passes through the etalon and a λ/2 waveplate and onto the grating stretcher where it is vertically displaced by a movable roof mirror and finally sent through a λ/2

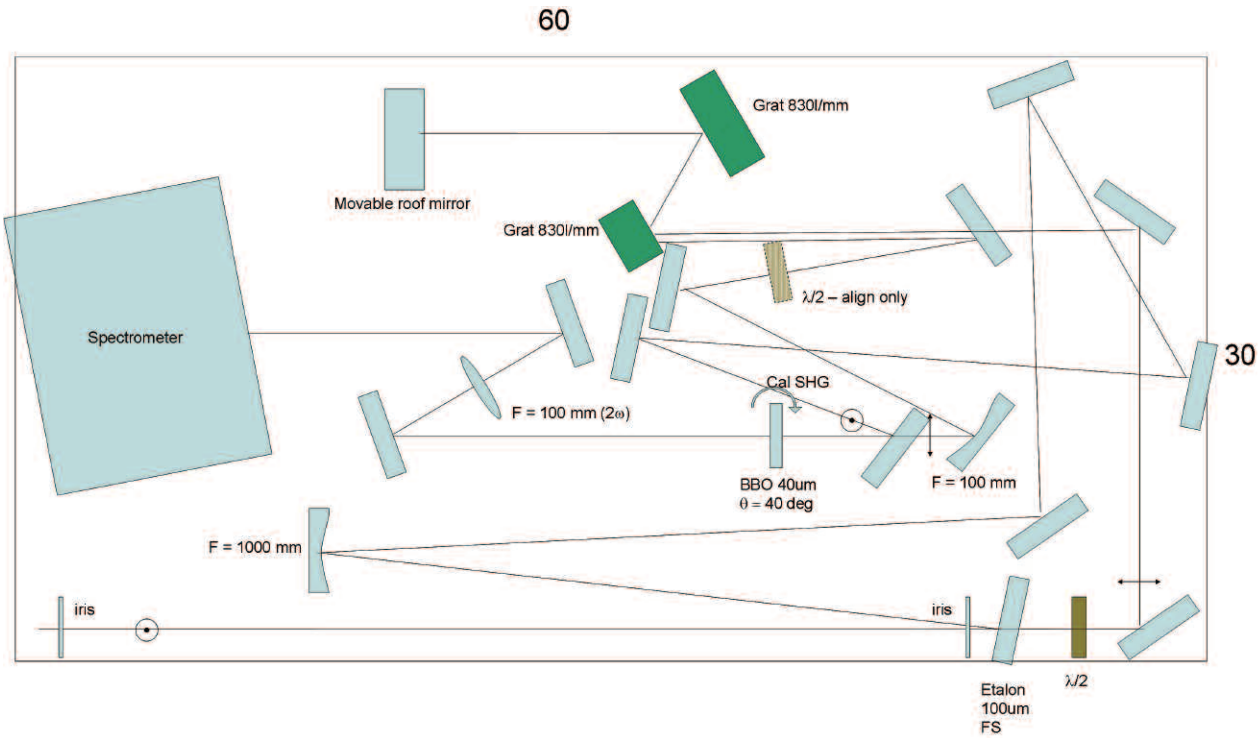

Figure 1. SPIDER schematic.

waveplate and onto the focusing mirror. The role of the first λ/2 waveplate is to increase the throughput of the stretcher because the gratings have higher diffraction efficiency for horizontally polarized beams. The role of the second waveplate is to help with the alignment.

Both beams intersect at the BBO crystal (thickness 40 µm, cut θ = 41°) where they are upconverted. The upconverted beam is imaged onto the spectrometer by an f = 100 mm achromatic doublet lens.

Setup

To align the SPIDER, one must make sure that the pulse pair and the stretched pulse overlap in space and time, and that the crystal is set to the right phase matching angle. First, both the beams impinging onto the crystal are set to vertical polarization (by a use of 2nd waveplate) corresponding to a Type I interaction, than they are visually overlapped on the crystal and the crystal is sequentially rotated to obtain SHG in each of the beams and then is set just between these two positions. Then the delay between pulse pair and stretched pulse is changed until the sum frequency is generated. Finally, after the energy in the converted beam is maximized, the crystal is rotated for a Type II interaction and the polarization of the stretched pulse is changed by 90°. The generated beam is than imaged onto the entrance slit of the spectrometer and the SPIDER trace is recorded.

The calibration trace is obtained by rotating the crystal to get SHG in the beam with the pulse pair. This SHG signal is then imaged onto the spectrometer and the calibration trace is recorded.

Software

The software for the SPIDER is written in Labview. It reads data from the spectrometer and Fourier transforms them. Transformed data in ‘frequency space’ appear as one large peak, representing the shape of the spectrum, and one small peak, representing the fringe modulation. The small peak is extracted by a use of a windowing function which

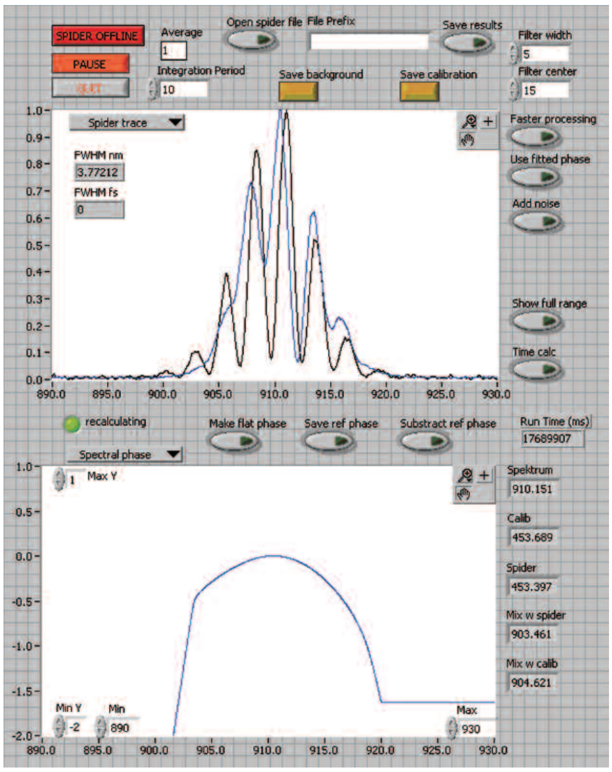

Figure 2. SPIDER program main window.

nullifies all data except for a small area around the small peak. Then the extracted function is transformed back. The same process is done with the calibration trace and the results are subtracted, yielding the spectral phase of the pulse. Both traces are recorded on second harmonic and need to be shifted to fundamental frequency for time domain computations (pulse shape). This wavelength calibration is done automatically by locating the maxima of fundamental and upconverted spectra. The fundamental spectrum, however, needs to be captured by another spectrometer. Then it is possible to calculate the time shape and phase of the pulse by applying another Fourier transform.

The code for this program was newly assembled, however, it still uses the original algorithm for extracting the phase developed by I. A. Walmsley [1], and the time domain calculations use part of the code developed by P. K. Bates.

Conclusions

By building the SPIDER diagnostic technique, the Vulcan 10 PW OPCPA project acquired a powerful device for characterizing ultra short pulses. This device will be used for setting up of the test compressor and for measurement of the pulses duration.

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References

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2. C. J. Hooker *et al*., CLF Annual Report, 192-193, (2003-2004).