

3 TW single-cycle pulses from a thin plate post-compressed OPCPA system

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Abstract: High quality 12 mJ pulses with 3.8 fs duration were produced by using the thin plate post-compression technique with 12 fs driver pulses from a 10 Hz OPCPA system operating at 820 nm central wavelength. © 2022 The Author(s)

1. Introduction

State-of-the-art lasers routinely generate ultrashort pulses with tens of mJ energy and sub-12 fs duration at a repetition rate of 1 kHz, providing peak intensities in the range of 10^{18} - 10^{19} W/cm² [1]. Particle acceleration [2] and high harmonic generation from solids [3] often require few-to-single-cycle pulses beyond the high peak intensity, which can improve the efficiency of the investigated processes. As a consequence, there is a huge demand to shorten the laser pulses with high efficiency, while the spatio-temporal quality is not distorted significantly on the target. Post-compression of linearly polarized pulses down to the single-cycle duration has been already demonstrated by spectral broadening in multiple dielectric thin plates (MPC) in the sub-mJ energy range with high optical efficiency [4,5]. Recently, the energy scaling was also explored down to 10 fs duration with 100 TW-class input pulses [6]. The single-cycle regime is an area, moreover, where the highest energy pulses have been reached via the use of hollow-core fiber only. In this paper we demonstrate the generation of 3.8 fs pulses in MPC, providing pulses with double the energy compared to the highest result so far [7].

2. Experimental technique and results

Our experimental setup was driven by the SYLOS Experimental Alignment laser system of ELI-ALPS [1], where the spectral broadening stage was built in a 4 x 1 m footprint vacuum chamber (Fig. 1, a, MPC). Laser pulses with 27 mJ, 10 Hz repetition rate and 12 fs duration were coupled to the MPC chamber after the beam transport system and the chirped mirror compressor.

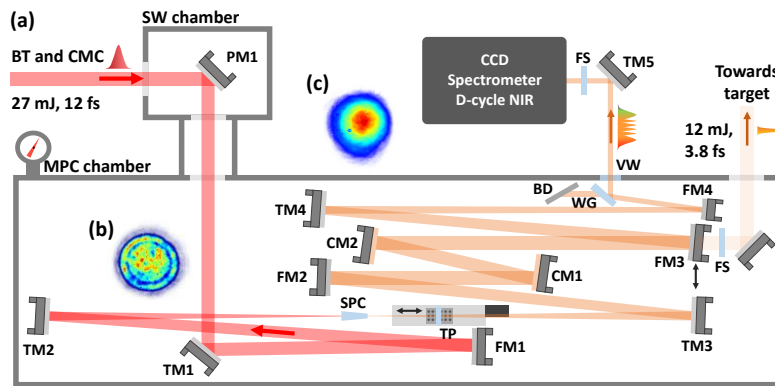


Fig. 1. Schematic view of the experimental setup (a), where PM1 is a piezo-controlled turning mirror, TM1-TM5 are turning mirrors, FM1-FM4 are focusing concave spherical mirrors, CM1-CM2 are chirped mirrors, TP is a thin FS plate, SPC is a glass cone, FS is fused silica, VW is a vacuum window. Near field spatial profiles on the input of the setup (b) and after spatial filtering (c) are shown as insets.

We realized a configuration with only a single piece of thin fused silica (FS) with a thickness of 500 μ m, which was AR coated on both surfaces for 450-1100 nm spectral range. Since the spectral broadening was performed in the intermediate field, the spatial intensity distribution required special attention: we improved the flat-top input beam profile incorporating diffraction rings due to the amplification stages (Fig. 1, b) by using a glass cone in the focus, i.e. the beam was spatially filtered. Special care was taken to optimize the input wavefront before the glass cone by using

the deformable mirror in the laser system. By using a focusing mirror with a focal length of 4 m, a high quality almost Gaussian intensity distribution was achieved with a transmission of about 50% (Fig. 1, c) after the cone. After spectral broadening, the beam was collimated for the original beam size by another 4 m focal length concave mirror. The collimated beam is reflected from a pair of custom tailored chirped mirrors for the spectral range of 550-1250 nm (PC2007, Ultrafast Innovations) and then propagated through a FS plate for final compression. The compressed beam can be sent to the target chamber, if mirror FM3 is moved out of the beam. In case FM3 is in the position, which is visualized in Fig. 1 (a), the beam is down-collimated to a beam size of about 15 mm by FM3 and FM4 focusing mirrors, then sampled by an uncoated wedge, and sent out of vacuum for final compression by using a 1.1 mm FS plate.

The compressed pulses were characterized in spatial, spectral and temporal domains. The resulting broadened spectrum was measured by combining a visible and a near infrared fiber-coupled spectrometer (Broadcom), and also by using an imaging spectrograph (MISS Large Broadband, FemtoEasy). Results of the fiber coupled spectrometer measurement show an extremely broad broadened spectrum spanning from 550 to 1180 nm at the 10^{-2} intensity level. The spatially resolved spectrum shows an even higher bandwidth on the blue side, namely the span ends at 510 nm at the 10^{-2} intensity level, while the red side is not resolved fully due to the detector limitation at 1110 nm. Temporal characterization was performed by a custom tailored scanning D-scan device developed for the spectral range of 500-1250 nm (D-cycle NIR, Sphere Ultrafast Photonics). We achieved the shortest pulses when the FS plate was positioned 39.5 cm from the focus, where the temporal duration was found to be as short as 3.78 fs FWHM with an energy content of 88% in the main peak (Fig. 2).

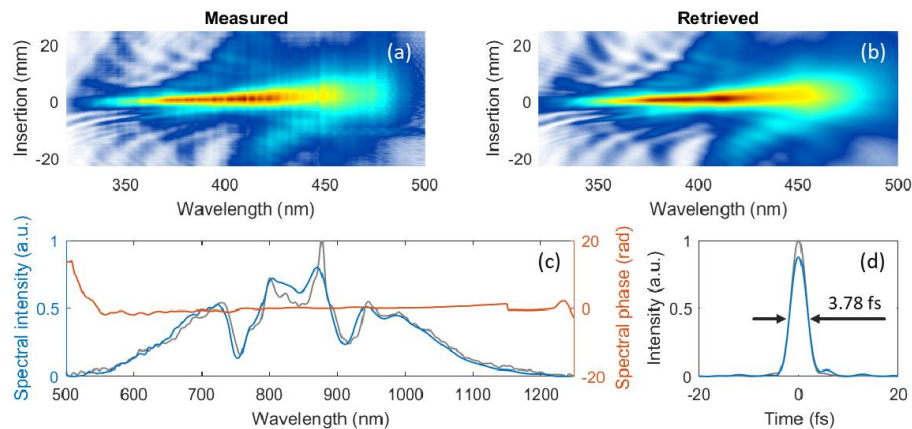


Fig. 2. Measured (a) and retrieved D-cycle traces (b), measured (grey) and retrieved fundamental spectra (blue) and spectral phase (c), and reconstructed pulse intensity profile compared to the transform-limited distribution (d).

Output pulse energy at the end of the spectral broadening stage was measured to be around 12 mJ after compression, which translates into a peak power of higher than 3 TW in pulses as long as only 1.4 optical cycles in both configurations.

3. Discussion

We demonstrated a method based on a single FS thin plate to compress 1 TW, 12 fs pulses to 3.78 fs with an increased peak power of 3 TW. Our technique relies strongly on the highly optimized spatial intensity distribution and wavefront of the input pulses, as well as the high initial temporal quality. Final compression was achieved by only using a pair of chirped mirrors with one bounce on each, and 1.1 mm of FS inserted to the beam. The produced 1.4-cycle pulses are the highest energy and highest peak power wave packets generated up to date, to the best of our knowledge. First application of these single-cycle pulses will be to generate neutrons from solid targets. Energy scaling of the method is under investigation by advanced 3+1D numerical simulations.

References

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