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Experimental demonstration of a temporal pulse shaping method based on nonlinear chirp

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Abstract. We present a general temporal shaping method based on spectral phase-only modulation for ultrafast laser sources. We explain the working principle of this technique and use it experimentally to generate a ramp-shaped pulse at the output of a laser source delivering 30 μJ 200 fs pulses at 500 kHz. This pulse is then launched inside a multipass cell to demonstrate non-linear wavelength shifting. A spectral tunability of 11 nm around the center wavelength of 1030 nm is achieved.

1 Introduction

Spectral control and tunability is a key feature for ultrafast laser sources in various spectroscopy domains [1]. Yb-doped femtosecond amplifiers based on the chirped-pulse amplification (CPA) scheme are extensively used as front-ends delivering high power and high energy pulses in the near infrared. Subsequent nonlinear optics stages allow to modify the temporal and spectral properties. For instance, Self-Phase Modulation (SPM) is often used to broaden the spectrum and reduce pulse duration. Multi-Pass Cells (MPC) have emerged as a flexible and efficient implementation for these setups [2, 3]. Other nonlinear optics effects such as Raman shifting have been implemented inside MPCs [4]. Coupling a pulse shaping stage with nonlinearity inside a MPC adds another degree of freedom on the output source capabilities [5, 6]. A recent example is the use of an asymmetric pulse shape combined with SPM to perform wavelength shifting [7]. In this work, we present a non-iterative approach of temporal pulse shaping based on nonlinear chirp and experimentally demonstrate wavelength shifting inside an MPC with a laser source delivering 30 μJ 200 fs pulses.

2 Temporal pulse shaping

The presented technique is the generalization of a method devised for the generation of square-shaped pulses [8]. A sufficiently linearly- stretched pulse has a temporal shape that reproduces its spectral shape, with an expansion factor that depends on the magnitude of the constant second-order spectral phase. This linear group delay indices a linear time-frequency bijection. Our temporal shaping technique consists in nonlinearly modulating this group delay according to the ratio between the spectral intensity and the target temporal intensity. The calculated corresponding spectral phase is applied to the pulse through a pulse shaper. Because this method is solely based on spectral phase shaping, it does not introduce excess losses. It is general and can be applied to arbitrary shapes provided that the transients are slow enough compared to the available optical bandwidth.

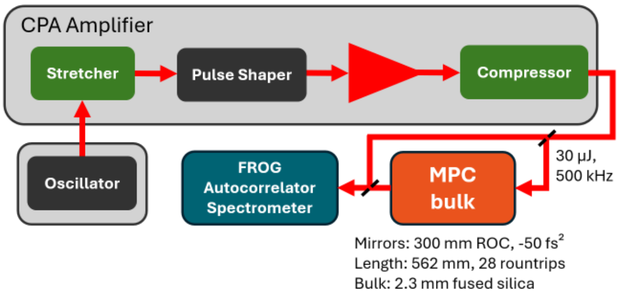

Fig. 1: Experimental setup for pulse shaping and wavelength shifting.

We implement this shaping technique on a CPA Yb-doped fiber laser source delivering 30 μJ 200 fs pulses (Fourier transform limit 190 fs) at 1030 nm and 500 kHz repetition rate. The setup is shown in Figure 1. The temporal characterization of the source when no shaping is applied are reported in Figure 2. We use a home-made FROG, a commercial spectrometer (Ocean Optics HR4000) and a commercial autocorrelator (APE PulseLink) for the temporal characterization. The phase mask is applied using a commercial fiber-coupled pulse shaper integrated inside the source. An example of the temporal intensity profile obtained for a ramp-shaped pulse is shown in Figure 3 (Top). The target pulse (purple) is a triangle with a slow edge and a vertical fast edge. The experimentally shaped pulse (orange) reasonably reproduces the target pulse. The corresponding experimen-

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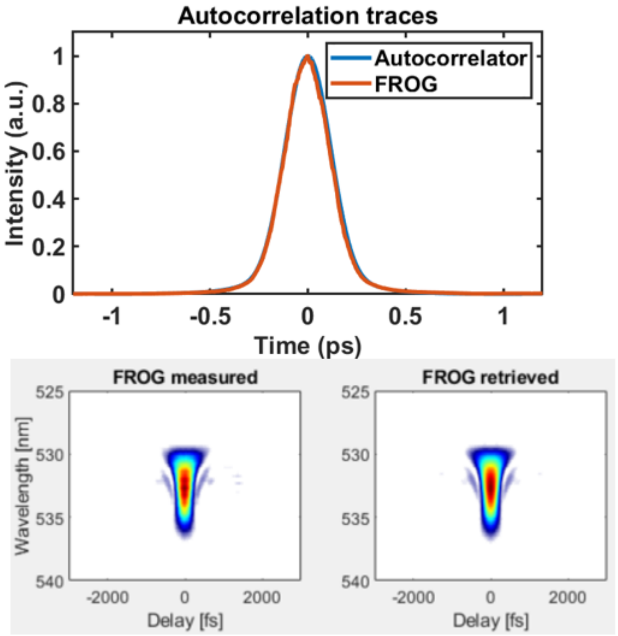

Fig. 2: Temporal characterization of the laser source. (Top) autocorrelation traces from the commercial autocorrelator (blue) and the FROG device (orange). (Bottom) Measured and retrieved FROG traces.

tally measured spectrum (black) and FROG retrieved spectrum (blue) and phase (orange) are reported in Figure 3 (bottom).

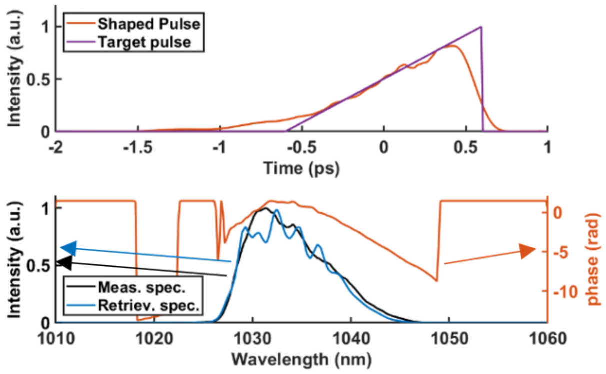

Fig. 3: (Top) ramp pulse shaping target (purple) and experimentally shaped pulse (orange). (Bottom) Corresponding measured (black) and FROG retrieved (blue) spectral intensities and shaped pulse spectral phase (orange).

3 Wavelength shifting via SPM in a MPC

We further demonstrate wavelength shifting by feeding the ramp-shaped pulses in a nonlinear MPC. The MPC parameters are reported in Figure 1, and features zero net GVD by combining a 2.3 mm-thick bulk plate of fused silica and two concave mirrors introducing a – 50 fs² group delay dispersion each. This ensures that the temporal shape is maintained along propagation in the MPC.

The results of the wavelength shifting are shown in Figure 4. We use the ramp-shaped pulse in Figure 3 to get the redshifted spectrum and a similar but temporally flipped version for the blueshifted spectrum. We measure a shift of the maximum spectral intensity of 4 nm for the blueshift (blue) and 7 nm for the redshift (red). This wavelength range of 11 nm is larger than the initial full width at half maximum of the laser of 8.5 nm.

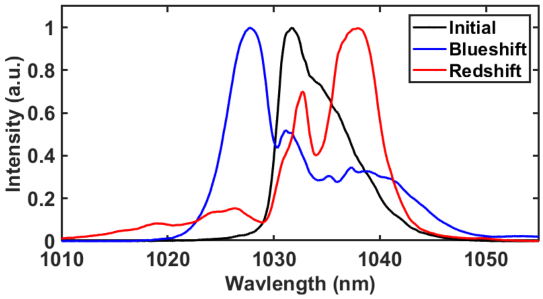

Fig. 4: Measured spectra at the MPC input (black) and at the output - blueshift in blue and redshift in red using the spectrometer.

Conclusion

We present the generalization of a method that allows arbitrary temporal pulse shaping based on introducing a deterministic nonlinear chirp. We experimentally demonstrate the method by generating a ramp-shaped pulse at the output of a 20 W, 200 kHz Yb-doped femtosecond source. A central wavelength tunability range of 11 nm is achieved via SPM at the output of a bulk MPC. The presented pulse shaping method is general and will be applied to different shapes to explore other applications with MPCs.

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