Pulse Compression: Toward Single-Cycle Pulse Generation

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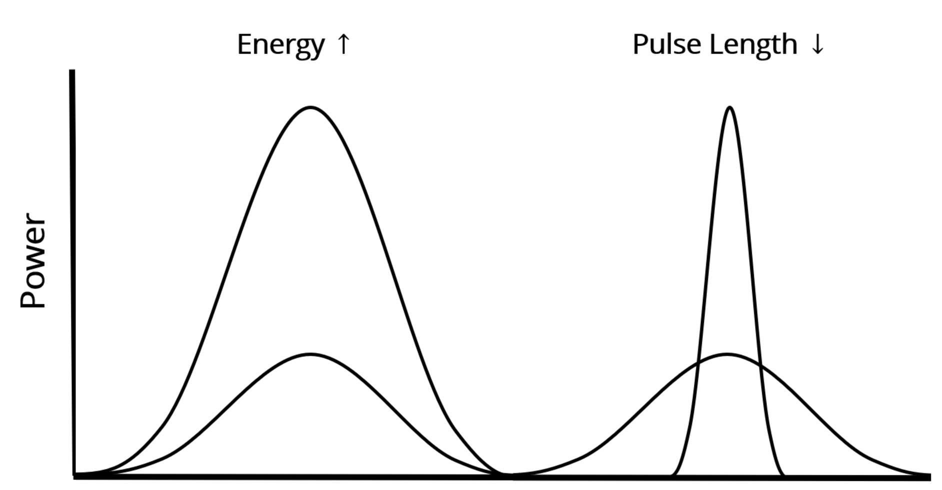
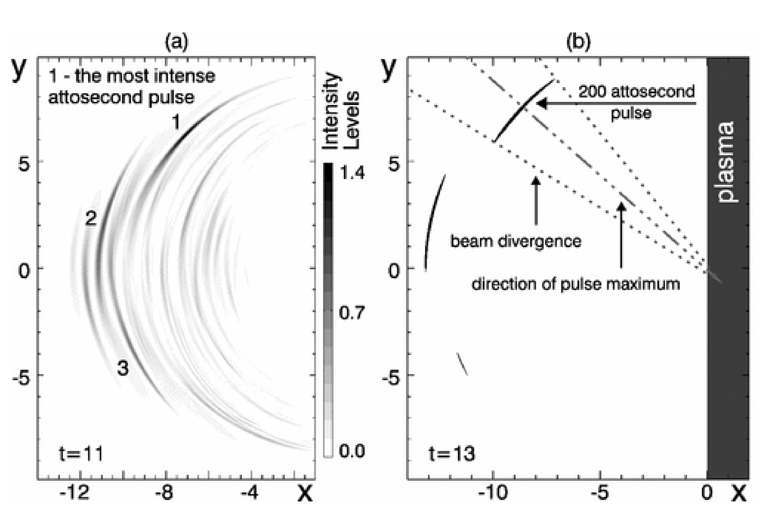
Abstract

Gaussian laser pulses of 800nm 6.63 mJ and 39 fs (~338 GW peak power) were spectrally broadened and subsequently compressed to 21 fs. The pulse energy was measured after the two fused silica targets positioned at Brewster's angle to be 6.55 mJ (~99% energy throughput).

Motivation

Thin Film Compression (TFC) has been proposed [1] as a means of increasing the peak power of ultrashort laser pulses. As opposed to increasing peak power by increasing the energy of the pulse, TFC instead achieves an amplification in peak power by compressing laser pulse length at a fixed energy. This pulse compression is accomplished by the generation of linearly chirped bandwidth through self-phase modulation.





Simulations show [2] that laser pulses compressed to the single-cycle regime have the potential to generate single-cycle x-ray pulses which could be used to generate wakefields in solid-density plasma with acceleration gradients of up to TeV/cm [3,4].

Compression scheme

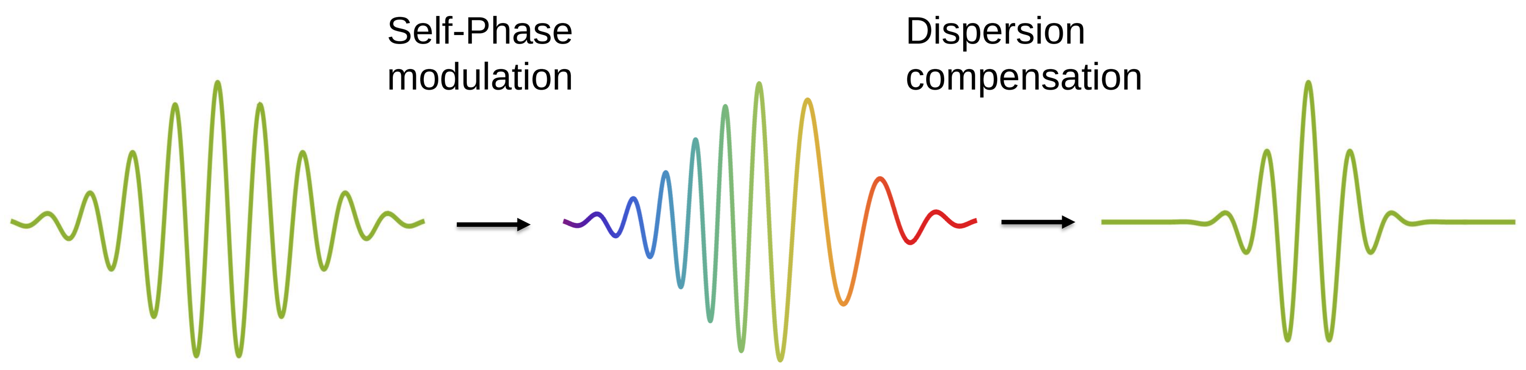
Self-phase modulation (SPM) is a nonlinear optical phenomenon that changes the index of refraction of a material in response high intensity fields through the Kerr effect. The instantaneous frequency is modified with respect to the time derivative of the intensity. In the case of gaussian pulses, this leads to a roughly linear chirp. Since the envelope of the pulse does not change through this process, the bandwidth of the pulse is wider, therefore contributing the spectral components necessary for a shorter pulse.

$$n = n_0 + n_2 I$$

$$\frac{d\phi}{dt} = \omega_{inst}(t) = \omega_0 - k_0 n_2 \frac{dI}{dt} z$$

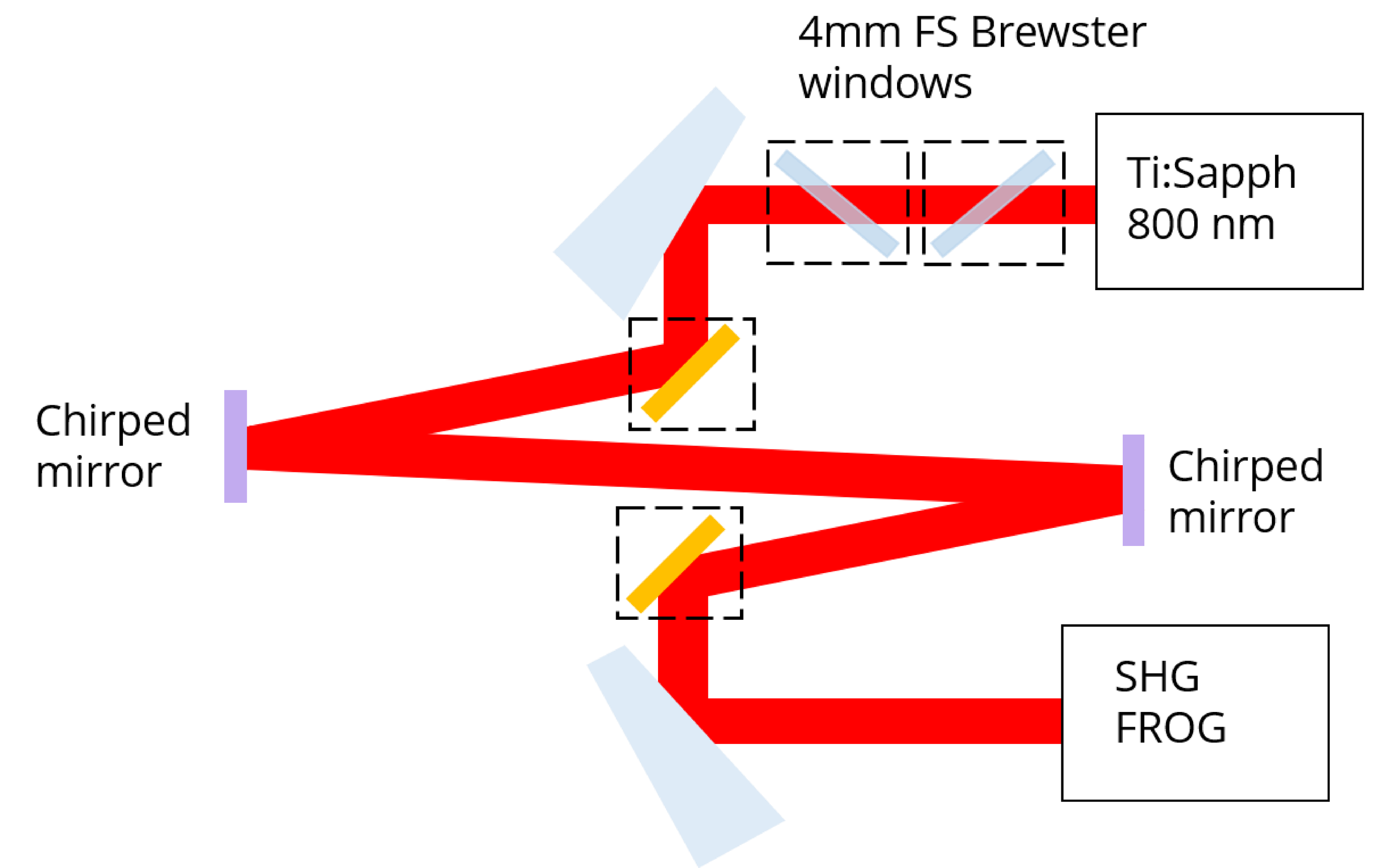
$$\phi(z,t) = \omega_0 t - \frac{\omega}{c}(n_0 + n_2 I) z$$

$$\Delta\omega_{inst}(t) \propto -\frac{dI}{dt}$$



This linear chirp introduced by SPM can be compensated with chirped mirrors, which then results in a shorter pulse.

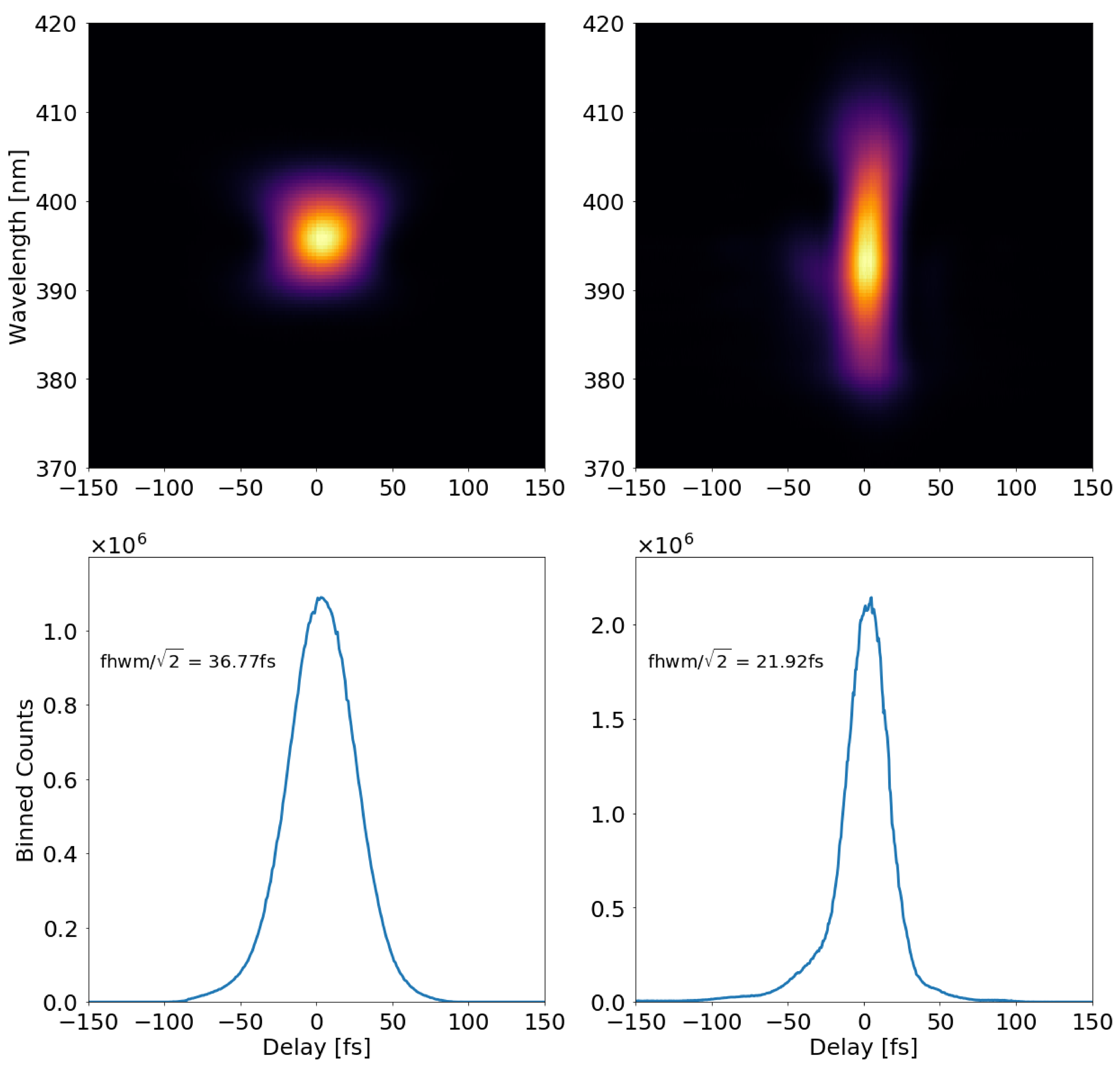
Experimental set-up



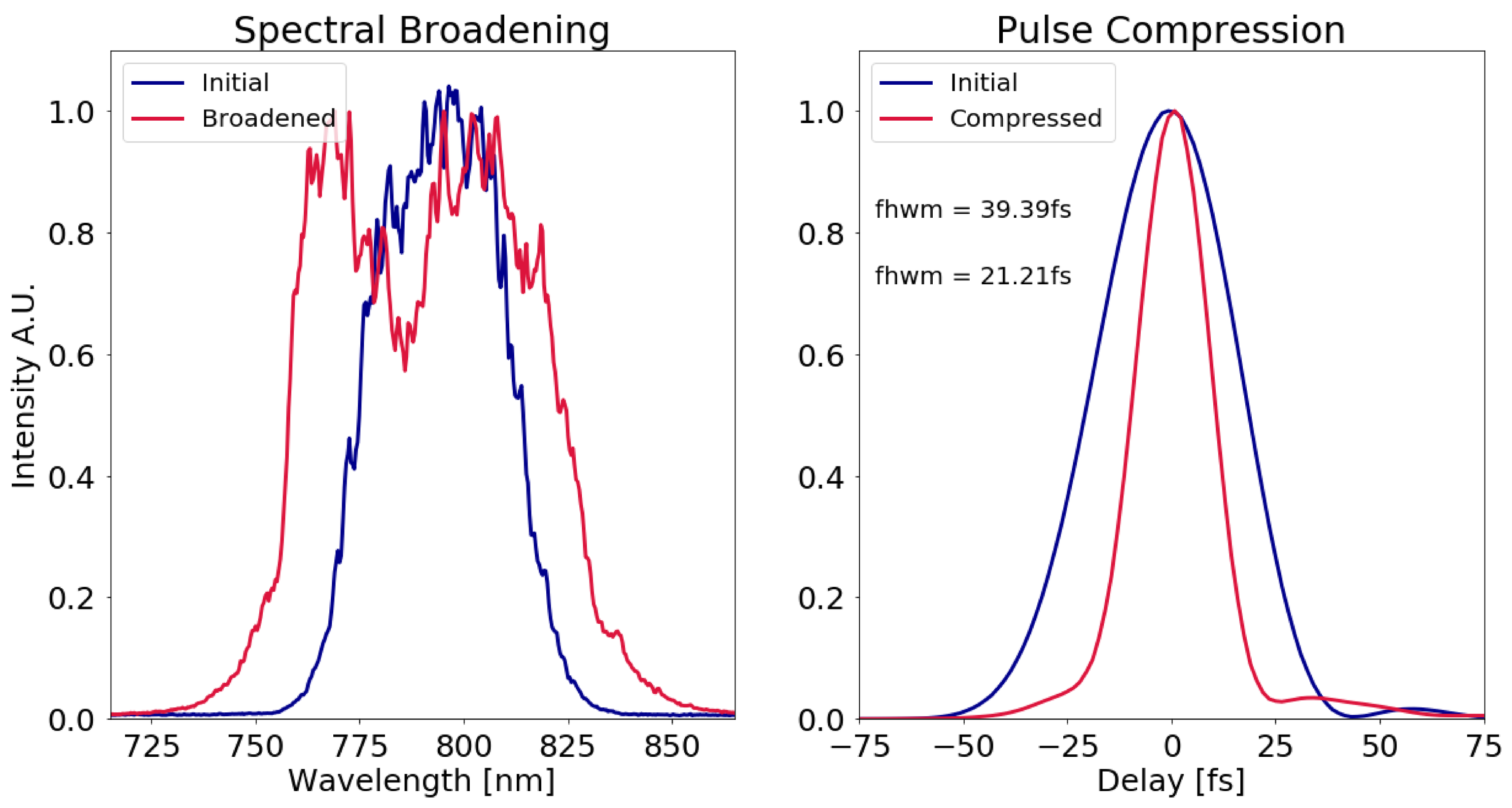
Laser pulses were sent through 2x 4mm fused silica windows at Brewster's angle (~9.72mm). The laser compressor was manipulated to optimize the spectral broadening through the targets. This broadened spectrum was then sent to 2x -250fs^2 chirped mirrors to compensate the chirp introduced through SPM. Wedges were employed to cut power to the diagnostics.

SHG FROG

Temporal measurements of the irised beam were obtained by a scanning SHG FROG. Seen below is the spectrogram and autocorrelation of the laser pulses without fused silica targets or chirped mirrors (left) and laser pulses with SPM and dispersion compensation through chirped mirrors (right). The second harmonic spectrum is broadened and the temporal duration is reduced.



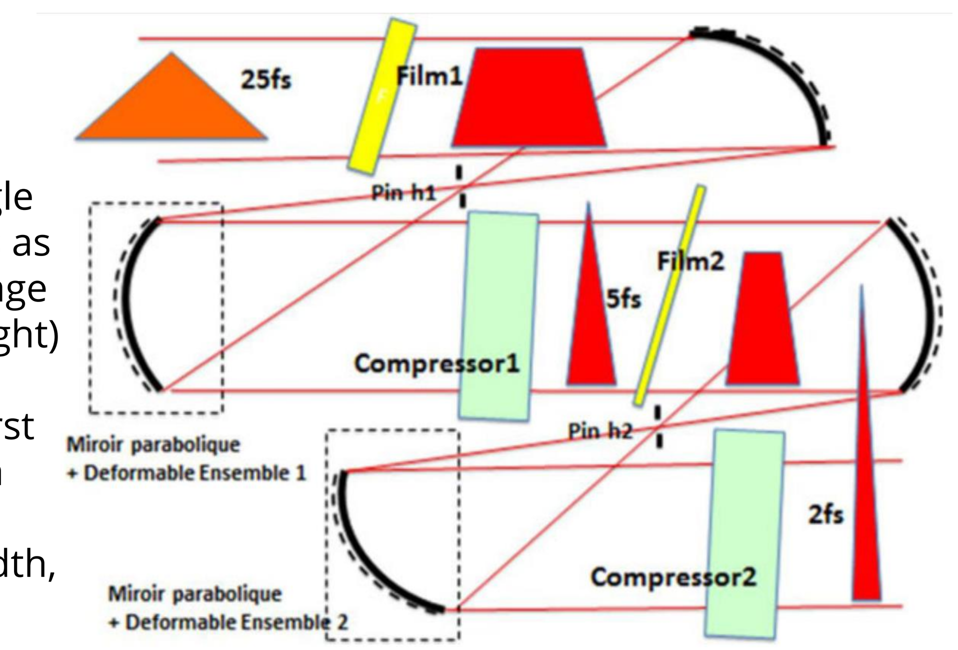
Spectral broadening and pulse compression

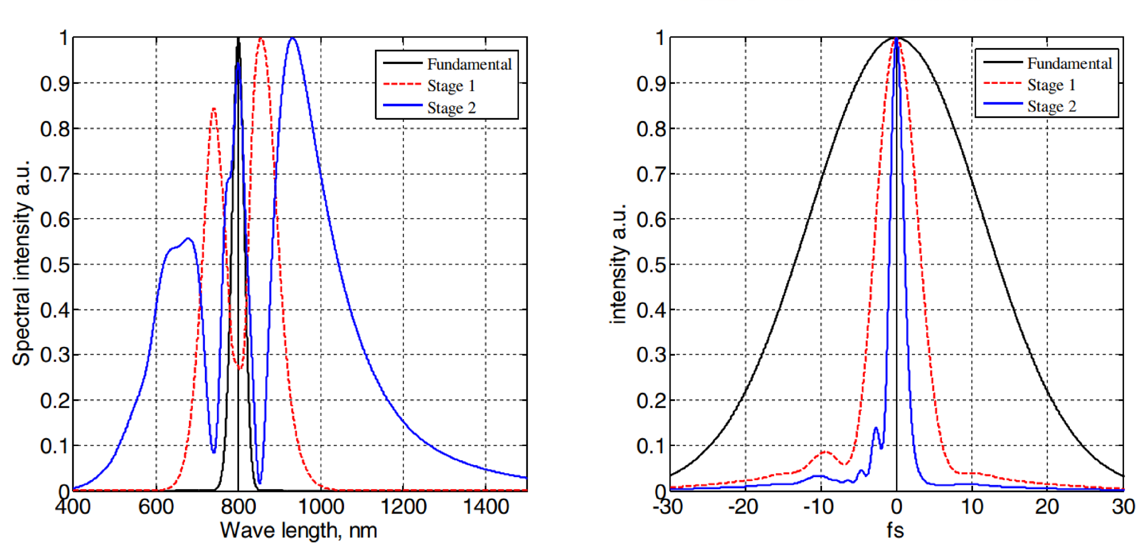


The spectrum before and after the fused silica targets was measured directly from a diffusive card (left). A phase retrieval algorithm was used to reconstruct the initial and compressed pulses (right) from the spectrogram measured by the scanning SHG FROG for the temporal measurement.

Future directions

Simulations have been performed in [1] that suggest that this process could be repeated to approach the single cycle regime. This work serves as a stepping stone to a multi-stage high efficiency TFC scheme (right) as suggested in [1]. Here the compressed pulse from the first stage would undergo SPM in a thinner material to generate more linearly chirped bandwidth, and be compressed again.





Seen to the left are the simulation results of the broadened bandwidth (left) and reconstructed pulse (right) from each stage of the TFC scheme.

References

[1] G. Mourou et al., Eur. Phys. J. 223, 1181 (2014)
[2] N.M. Naumova et al., Phys. Rev. Lett. (2004)
[3] T. Tajima, Eur. Phys. J. 223, 1037 (2014)
[4] X. M. Zhang et al., Phys. Rev. Accel. Beams (2016)

Acknowledgements

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