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# Generating Relativistic Intensities via Staged Pulse Compression in Dielectric Media

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**Abstract:** We demonstrate staging of self phase modulation in thin dielectric plates to produce a cost effective means of generating relativistically intense pulses. This new scheme has low loss and maintains focusability.

## 1. Introduction

Intense few cycle laser pulses have numerous applications for strong and high field science. Generating relativistic intensities is non-trivial, as issues such as gain narrowing and higher order dispersion make it practically difficult for sufficiently high laser energies. For this reason, pulse compression of the output laser pulses can be an efficient means of few cycle laser pulses. In most schemes, self phase modulation enables a laser pulse to experience bandwidth broadening such that dispersion correcting optics can compress the pulse. To compress higher laser energies, the pulse compressor must be able to accommodate larger beam diameters of at least one centimeter. While schemes utilizing thin dielectric plates as the nonlinear medium have been suggested to address these issues [1], the amount of pulse compression achieved experimentally in dielectric plates thus far has been insufficient to generate multi-millijoule level few cycle pulses in a single stage.

With this work, we demonstrate a new solid-state method to generate single cycle laser pulses that results from successive staging of pulse compression. Using a multi-millijoule, commercially available ultrafast laser system, up to three stages of pulse compression were demonstrated producing laser pulses with bandwidths to support a 1.5 cycle pulse duration. Additionally, the focal quality is minimally perturbed, such that we are able to maintain near diffraction limited spot sizes even when focusing with low f-number optics.

## 2. Results

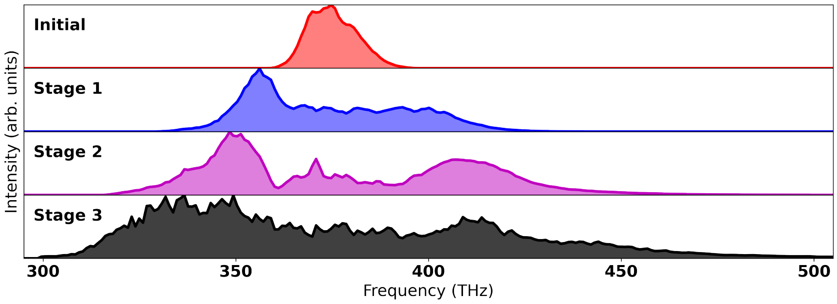

Fig. 1: a) Initial spectrum of the laser, with a FTL of 33 fs. b) Spectrum after one stage of broadening, with a FTL FWHM of 11 fs. c) Spectrum after two stage of broadening, with a FTL FWHM of 6 fs d) Spectrum after two stage of broadening, with a FTL FWHM of 4.1 fs

We use stages of pulse compression based on self-phase modulation in fused silica plates. Each stage is able to adjust the intensity of the Gaussian beam on the plate, and to filter out portions of the beam which do not undergo broadening. The pulse compression scheme can be optimized for a wide variety of input energies; we demonstrate efficient compression with laser energies of 0.95 and 6.9 mJ with initial durations of 33 fs. In each stage, approximately 8% energy loss was observed, with a similar decrease in peak intensity observed in the focal spot. A total of three stages to produce ultrabroadband spectrum.

The spectral broadening for each stage was quantified by measuring the dB-20 spectral width for the spatially averaged spectrum of the pulse. The first stage showed a broadening from 70 nm initially to 198 nm. The second stage and third stage broadened the pulse to 316 nm and 477 nm, respectively. These spectral widths reduce the transform limited pulse duration from 33 fs for the initial pulse to 11 fs from the output of the first stage, 6 fs for the output of the second stage, and 4 fs for the output of the third. The pulses were compressed using chirped mirrors and the pulse duration was measured using transient grating frequency resolved optical gating. The output of the second stage was measured to be 7 fs, nearly the spectrum's Fourier transform limit of 6 fs.

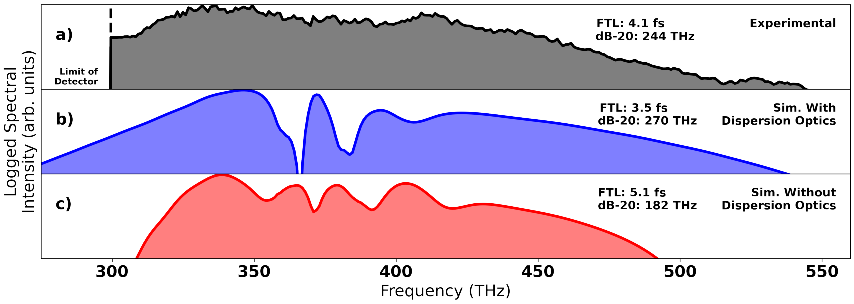

Fig. 2: Effect of Compression Error. a) Experimental measured spectrum after 3 stages. Spectral width was 244 THz at the dB -20 level, corresponding to a FTL pulse duration of 4.1 fs. b) Simulations of experimental setup including the -90 $fs^2$ and -32 $fs^2$ of dispersion compensation after the first two stages. c) Simulations without the usage of dispersion compensation. The same on target intensity was maintained on the fused silica.

The intensity of the pulse was characterized by a fast f/2 off-axis parabolic mirror. The full-width at half-maximum focal diameter of the unbroadened beam had a near diffraction limited spot size of $\sim$ 2 microns. The compressed output of the second stage of compression produced a nearly identical spot size, changes in the beam diameter were on the order of the error bars of the measurement of 0.1 microns. Each stage produced a broadening on the order of a factor of 2 to 3. Including losses, two stages increases the focused intensity by a factor of 4.

Strong and high field experiments were produced with the output of the staged pulse compression, demonstrating the stability and robust nature for few cycle laser plasma interactions. Intensities were varied between $10^{15}$ and $10^{18}$ $Wcm^{-2}$ with the identical pulse compressor, producing quasi-continuum x-rays and MeV energy electrons. Furthermore, the entirety of the optics and opto-mechanics necessary for implementing such a scheme are commercially available and were purchased for a total cost below three thousand dollars (US).

## 3. Conclusion

In this work, we have demonstrated a cost effective, robust means of pulse compression capable of supporting single cycle laser pulses using staged self-phase modulation in dielectric plates. With larger bandwidth chirped mirrors, peak powers of 1 TW can be achieved from the output of a single laser amplifier. Additionally, the focusability is preserved such that relativistically intense laser pulses can be achieved at the kilohertz repetition rate. This makes it an ideal source for the study of high intensity, relativistic laser-plasma interactions like relativistic solid density high harmonic generation [1].

## Acknowledgements

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