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Spectral Compression of Intense Femtosecond Pulses by Self Phase Modulation in Silica Glass

Krzysztof Iwaszczuk, Binbin Zhou, Morten Bache and Peter Uhd Jepsen
DTU Fotonik, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark
kiwa@fotonik.dtu.dk

Abstract: We experimentally demonstrate spectral compression of mJ fs pulses by self phase modulation in silica glass. Spectral narrowing by factor 2.4 of near-transform-limited pulses is shown, with good agreement between experiment and numerical simulation.

OCIS codes: (320.2250) Femtosecond phenomena; (320.5540) Pulse shaping; (190.7110) Ultrafast nonlinear optics; (320.1590) Chirping.

1. Introduction

Self phase modulation (SPM) is commonly associated with spectral broadening of a pulse propagating in a nonlinear medium. However, SPM can also be utilized to narrow the spectrum of a propagating pulse. It has been previously shown that negatively chirped near infrared (NIR) nanojoule pulses propagating in optical fibers experience SPM which can lead to a spectral compression [1-2]. Those effects have been studied in various types of fibers, including single mode [1-3] and photonic crystal [4-5] fibers, with lengths ranging from tens of cm to several km. In this work we apply the same principle to millijoule pulses from a femtosecond laser amplifier propagating in silica glass rods and show that this method can provide an inexpensive alternative to a dual pulse duration laser amplifier. Applications of the spectral compression include low loss generation of intense 100-300 fs transform-limited pulses from sub 35 fs pulses and the use of these spectrally compressed pulses for efficient terahertz radiation generation by tilted wavefront method in lithium niobate [6].

During pulse propagation in silica glass in the normal dispersion regime, SPM causes energy redistribution between different spectral components. The leading edge of the pulse is being frequency downshifted, while the trailing edge experiences frequency upshift. As a result, for negatively chirped pulses, energy of both the short and the long wavelengths is shifted towards the central wavelength. For positively chirped pulses the effect is opposite and leads to spectral broadening.

2. Results

A regenerative Ti:sapphire femtosecond laser amplifier (SpectraPhysics Spitfire) delivers 2.4 mJ pulses with center wavelength of 800 nm and a pulse bandwidth of 33.4 nm in full width half maximum (FWHM) of intensity. The internal grating compressor is used to control the initial chirp of the NIR pulses. The shortest pulses achievable after compression have 60 fs autocorrelation trace FWHM, which is 1.49 longer than the shortest pulses supported by the 33.4 nm spectrum. The autocorrelation trace reveals a large pulse pedestal, which is an indication of significant third (TOD) and fourth order phase dispersion (FOD). The laser beam with diameter of 5.4 mm, defined by the FWHM of its intensity, is incident onto high-purity silica glass rods of lengths between 20 and 200 mm. An autocorrelator and a fiber coupled spectrometer are used to characterize pulses transmitted through the glass.

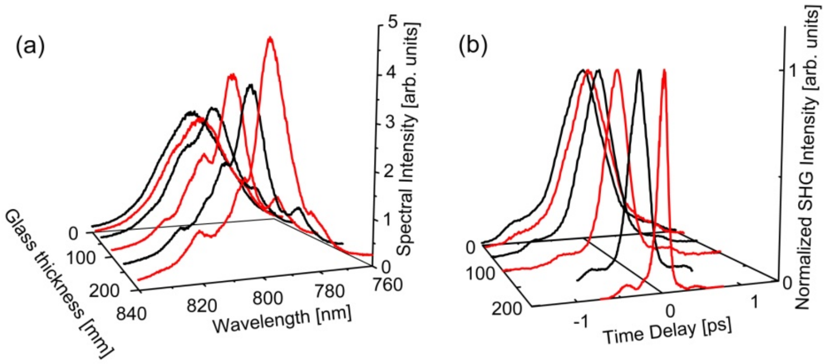

Fig. 1. Experimental spectral compression in silica glass of strongly negatively chirped 2.4 mJ pulses with 800 fs AC width. (a) Output spectra (b) normalized intensity autocorrelation traces of pulses transmitted through silica glass rods of a different thickness.

Figures 1(a) and 1(b) show correspondingly measured spectra and autocorrelation (AC) traces of NIR pulses transmitted through silica glass rods. The incident pulse is strongly negatively chirped and has AC trace width of 800 fs (FWHM). While propagating through the material the pulse duration decreases. Simultaneously energy from the wings of the spectrum is being transferred to the central part and its spectral intensity increases.

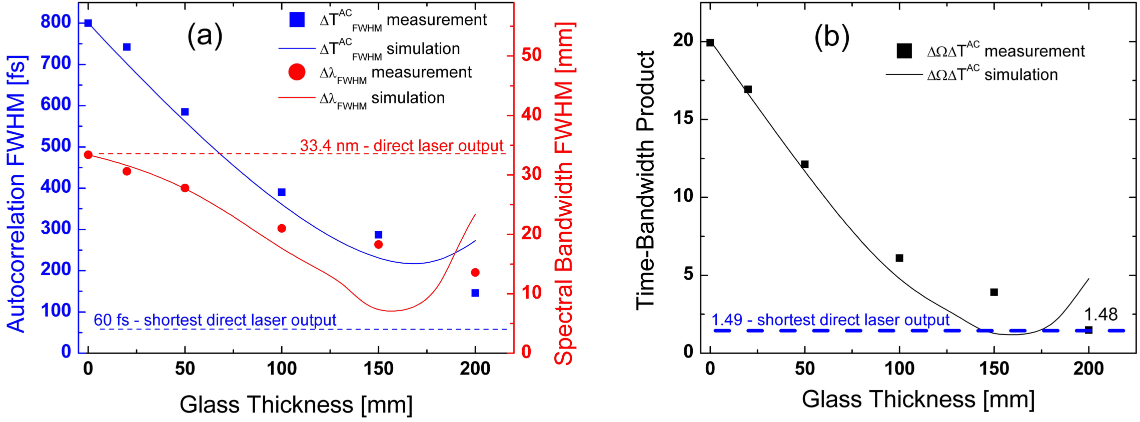

Fig. 2. (a) Autocorrelation FWHM and spectral bandwidth FWHM of 2.4 mJ pulses transmitted through glass rods of various thicknesses. Red dashed line – spectral width of uncompressed pulse directly from the laser amplifier. Blue dashed line – shortest achievable pulse duration directly out of the laser. (b) Time-bandwidth product of pulses transmitted through glass rods of various thicknesses. Blue dashed line – time-bandwidth product for shortest pulse directly out of the laser amplifier.

Figure 2(a) shows the result of measurement and numerical simulation of the spectral bandwidth and pulse duration for pulses propagation through silica glass. Numerical simulations are performed using a generalized nonlinear Schrödinger equation in the slowly evolving wave approximation, and included self-steepening, space-time focusing, full dispersion from the Sellmeier equation, and a standard delayed Raman term with 18% strength and a total Kerr nonlinearity of n_2=3.5x10^{-20} m^2/W. The 3+1D simulations were done with a split-step Fourier scheme. The spectral input phase was chosen to include 2nd order dispersion alone (a total GDD of -5750 fs^2 was used on a Gaussian spectrum with 33.4 nm FWHM to get an 800 fs AC FWHM), even if we had some indications of higher-order contributions to the input phase. Such prepared pulse is launched into the silica glass. The simulation shows that most of the on-axis propagation dynamics is governed by the interplay between material dispersion and pulse phase, while the intensity turned out to be low enough to avoid filamentation for such short propagation distances. Good agreement between measurement and simulation is clear in the range 0-120 mm. The differences for the remaining glass length could be at least partially explained by ambiguity in the choice of the pulse input phase; we saw a different dynamics when incorporating higher-order terms in the phase. Fig. 2(b) shows time-bandwidth product (TBWP), defined as the product of the 1/e intensity of time and angular frequency (according to which a Gaussian bandwidth-limited pulse has TBWP of 1). Our spectral compression method is able to deliver pulses with TBWP as low as 1.48 so basically the same as the TBWP of the shortest pulse directly out of the laser amplifier.

3. Conclusions

We have experimentally demonstrated efficient spectral compression of intense femtosecond near-infrared pulses in silica glass. A spectral compression factor of 2.4 has been achieved, with the peak increase of the spectral intensity of 1.7. Ongoing work is focused on reduction of higher order dispersion in the input pulse which will allow even stronger compression and result in better agreement between theory and measurements.

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