Tilted Transmission Grisms for Pulse Compression with Dispersion Control Up to the Fourth Order

N. Forget, S. Grabielle and P. Tournois
FASTLITE, Les Collines de Sophia Bât. D1, 1900 route des Crêtes, 06560 Valbonne, France
**Corresponding author:.forget@fastlite.com*

Abstract: We demonstrate a grism compressor designed to compensate the second, third and fourth order dispersions of a 1.5m SF57 stretcher at 800nm.

OCIS codes: (320.5520) Pulse compression; (320.7090) Ultrafast lasers

1. Introduction

The recent spread of double-CPA architectures in high-intensity, high-contrast and/or few-cycle Ti:Saphire laser systems has renewed the interest in bulk stretchers and, subsequently, in grism-based compressors. In most double-CPA architectures, the first CPA is typically a CPA laser system delivering mJ-level sub-25 fs pulses which are then spectrally reshaped, cleaned or broadened in a nonlinear stage and then seeded in a high-energy second CPA. The additional complexity of the double-CPA architecture and the high sensitivity of the nonlinear stage to all possible fluctuations of the spectral phase and pulse energy plead for schemes as simple, as compact, as stable as possible for CPA1. Additionally, the coherent pulse contrast and the carrier-envelope phase stability are key parameters of CPA1.

The use of bulk stretchers considerably simplifies the overall design, footprint and stability of moderately dispersive CPAs, i.e. CPAs in which the stretching ratio (chirp) doesn't exceed a few ps/nm. In the near infrared (typically 700-900nm), propagation lengths of the order of 1m are required even with highly dispersive glasses such as SF57ultra (Schott). Nevertheless, with the help of internal reflections, it is possible to fold the beam path and reach such propagation distances within compact devices (Fig.1a). For sub-25fs input pulses, such bulk stretchers provide stretching factors of a few thousands, which is large enough to sustain stimulated laser amplification up to the mJ-level. Bulk stretchers provide rock-stable CEP stability, high throughput and avoid spectral clipping issues.

A major property of bulk stretchers is the sign of the third order dispersion (TOD), which is, as for the second order dispersion (GDD or chirp), positive. Consequently, a Treacy compressor cannot be used to compensate both GDD and TOD since, for a grating pair, GDD is negative whereas TOD is positive. As soon as 1968, it was shown that TOD could be cancelled or reversed by replacing reflective gratings by transmission gratings engraved on the surface of prisms [1-2]. We have previously demonstrated that assemblies of high index prisms and transmission gratings could compensate for both the GDD and TOD of long bulk stretchers and retain favourable properties for a pulse compression device [3-5]: high efficiency (~60% in double-pass), compactness, low-level of nonlinear effects even at the multi-mJ level (8 mJ [6]). However, the large level of fourth order dispersion (FOD) introduced by the compressor had to be compensated by an acousto-optic dispersive filter.

In this talk we introduce an additional degree of freedom with respect to the previous design: the prisms are tilted with respect to the planes of the gratings. We demonstrate both numerically and experimentally that with this new degree of freedom, the FOD of a bulk stretcher can also be compensated by a grism compressor. As a proof of concept, we measure the spectral phase of a ~1.47 m SF57ultra bulk stretcher combined to a tilted-grism compressor over the 720-900 nm bandwidth and show that the residual phase is mainly limited to the fifth order.

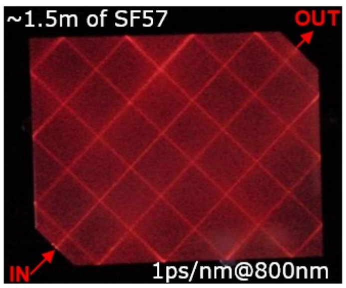
2. Experimental setup

The bulk stretcher is a 15x17x2.5cm^3 block of SF57ultra (Schott) with two corners cut at 45°. After 14 total internal reflections the total propagation length is ~1.47m. The estimated GDD, TOD and FOD are 330 000 fs^2, 200 000 fs^3 and 80 000 fs^4. The overall transmission is >80% over the full spectral bandwidth. The grism compressor comprises two parallel transmission Bragg gratings (1282 g/mm) and two anti-parallel isosceles SF57 prisms with an apex angle of 53° (Fig.1b). All surfaces are AR-coated for S polarization over the 720-900nm bandwidth. An IntegralPro-100 (Femtolasers) femtosecond oscillator delivering 200nm band pulses at 800nm was used for the experiments.

3. Results

The group delay functions of the stretcher and compressor were separately measured over 700-900nm by a variant of spectral interferometry: the elements were inserted in the probe arm of large-scale Mach-Zehnder interferometer and the spectral interferogram was recorded with a spectrometer as a function of the length of the reference arm. The group delay functions could be retrieved with ±60fs and ±0.1THz accuracies in the time and frequency domains respectively. The experimental data are shown in Fig.2a. The slopes and curvatures of the group delay functions are clearly of opposite signs. The residual group delay expected when combining the stretcher and compressor was first estimated by computing the sum of the two group delay functions: the residual group delay is well below 1ps.

a)



b)

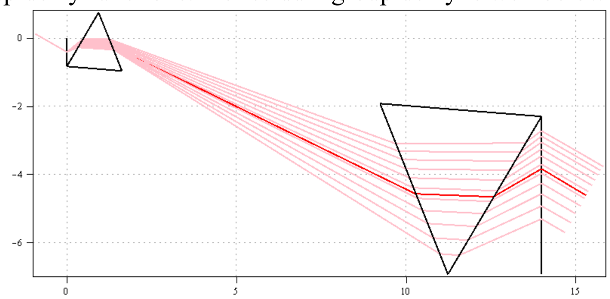
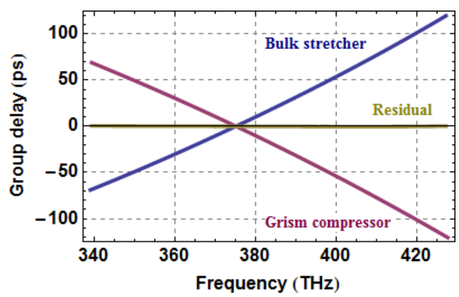


Fig.1: Left: view of the bulk stretcher (HeNe beam). Right: sketch of the tilted-grism compressor (units are cm).

The stretcher and compressor were then both added in the probe arm of the interferometer and the residual spectral phase was retrieved by Fourier-transform spectral interferometry (Fig.2b). The residual phase is a 5th order polynomial.

a)



b)

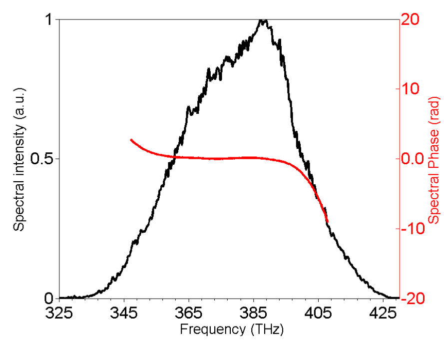


Fig.2: Left: group delays as a function of frequency. Right: input spectrum and residual phase (stretcher+compressor).

4. Conclusion and prospects

Tilted-grism compressors based on transmission gratings and high index prisms open the path to efficient and broadband compression schemes with adjustable GDD, TOD and FOD. Such compressors could be matched to compensate the dispersion of bulk/fiber stretchers (and/or laser amplifiers) up to the fourth order, which opens the path to compact and CEP-stable CPAs sustaining sub-20fs pulses with adjustable GDD, TOD and FOD (Fastlite patent pending).

[1] P. Tournois : « Sur un interféromètre de phase à variation linéaire du temps de retard en fonction de la fréquence » C.R. Acad. Sc. Paris, 269, 455-458 (1969).
[2] P. Tournois, "New diffraction grating pair with very linear dispersion for laser pulse compression," Electron. Lett. **29**,1414–1415 (1993).
[3] N. Forget, V. Crozatier, P. Tournois, "Transmission Bragg-grating grisms for pulse compression," Appl. Phys. B 109, 121–125 (2012).
[4] A. Ricci and A. Jullien and N. Forget and V. Crozatier and P. Tournois and R. Lopez-Martens, "Grism compressor for carrier-envelope phasestable millijoule-energy chirped pulse amplifier lasers featuring bulk material stretcher", Opt. Lett. 37, 1196 (2012).
[5] A. Ricci, A. Jullien, J. P. Rousseau, and R. Lopez-Martens, "Front-end light source for a waveform-controlled high-contrast few-cycle laser system for high-repetition rate relativistic optics," Appl. Sci., 3(1), 314–324 (2013).
[6] A. Ricci, A. Jullien, J.-P Rousseau, F. Böhle, S. Grabielle, N. Forget, P. Tournois and R. Lopez-Martens, "High-contrast, CEP-controlled double-CPA laser", submitted to CLEO 2014, SI2