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Ihsan Fsaifes, Claude-Alban Ranély-Vergé-Dépré, Rezki Bechecker, Kilian Fritsch, Oleg Pronin, et al.. Post-compression of shaped coherent beam combining femtosecond digital laser pulses. *Advanced Solid State Lasers, Optica*, Oct 2023, Tacoma, United States. pp.ATH3A.1, 10.1364/ASSL.2023.ATH3A.1 . hal-04778589

HAL Id: hal-04778589

<https://hal.science/hal-04778589v1>

Submitted on 12 Nov 2024

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Post-compression of shaped coherent beam combining femtosecond digital laser pulses

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Abstract: We present the post-compression of 337 fs/123 W pulse train generated from a 61-tiled channels coherently combined femtosecond digital laser in an Argon-filled multi-pass cell. We also explore the propagation of a Laguerre-Gaussian beam in such a cell. © 2023 The Author(s)

1. Introduction

A wide field of applications ranging from materials processing, high-field physics to medicine and biology require high average and peak powers ultrashort femtosecond laser pulses [1]. In this context, we have built XCAN; a 61 tiled channels coherent beam combining (CBC) femtosecond digital Yb-fiber laser. Each channel acts as an individual pixel where amplitude and phase are controlled independently, allowing a fast beam shaping [2,3]. The XCAN laser developments are pursued through the NanoXCAN project aiming at developing a new X-ray nanoscope by concentrating the laser electric field on metallic nanoparticles up to the relativistic regime, producing energetic hard X-rays. However, a Laguerre-Gaussian beam with a pulse duration shorter than 400 fs is needed to generate a needle beam exhibiting an ultra-long depth of field, subwavelength transverse confinement, and polarization oriented along the longitudinal direction [4]. To this purpose, two cascaded post-compression stages are considered to reach a final pulse duration around 10 fs, starting from 300-400 fs. To preserve the XCAN digital laser mode operation and to guarantee a high energy throughput, nonlinear pulse compression in gas-filled MultiPass Cells (MPCs) is considered instead of hollow-core fibers (HCFs) [5]. The nonlinear process involved in the post-compression shall also improve the contrast of the XCAN laser. In this paper, we will present and discuss first results, on one stage post-compression of Gaussian and first-order helical Laguerre-Gaussian (LG) beams generated by the 61-tiled channels coherently combined.

2. Experimental setup and results

The XCAN architecture relies on a tiled-aperture configuration, where 61 polarized Yb-fiber amplifiers are placed side-by-side as close to each other as possible in a planar hexagonal array arrangement (Fig. 1). The master oscillator delivers 220 fs pulses at a repetition rate of 55 MHz, temporally stretched to 2.5 ns. The repetition rate is then decreased down to 333 kHz to increase the pulse energy. The estimated B-integral accumulated in the Yb-fiber amplifiers is ~ 3 rad. The CBC is achieved when focusing the composite pupil with a single lens. The phase stabilization (at ~ 1 kHz) is performed using an interferometric measurement method with active phase control and a stochastic parallel gradient descent (SPGD) algorithm implemented on a FPGA. When applying a helicoidal phase $\exp(i l \theta)$ distribution to the 61-channels, a Laguerre-Gaussian beam (donut shape) characterized by its topological charge l is generated (Fig. 1: right).

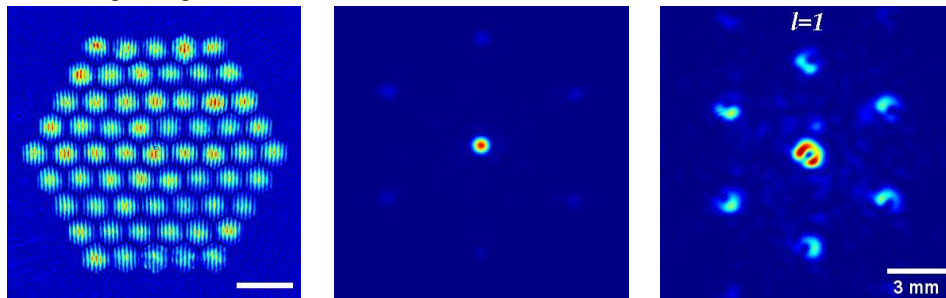


Fig. 1: Experimental near field interference pattern of 61 beamlets as operated on XCAN (Left). Experimental far fields with a flat phase (Center) and for an azimuthal order $l = 1$ LG beam (Right).

To maintain a stable CBC efficiency and beam pointing stability, the XCAN laser incorporates a complete active thermal cooling system. However, MPCs tolerate some beam pointing instability, typically less than 10 % of the beam diameter which is in good agreement with our CBC beam; allowing thus a stable post-compression operation.

The combined and spatially filtered beam is temporally compressed by using a 1760 l/mm multilayer dielectric reflection grating pair with an overall transmission of 84 %, resulting in a compressed pulse duration of 337 fs (Fig. 2), 123 W average power and 0.37 mJ pulse energy. The compressed beam is then directed to the MPC provided by n2-Photonics and tailored to withstand 500 W average power and up to 1 mJ energy per pulse. The MPC relies on a pair of concave 2" mirrors with 600 mm radius of curvature at a distance of 116 cm from each other. The beam experiences a total of 17 round-trips through the 3.8 bars Argon filled cell. The transmission of the MPC is measured to 99 %, a value not considering the foreseen losses of the chirped mirrors based compressor (not yet in place at the time of this submission, losses expected to be less than 5%). At the MPC input, the laser beam is mode matched to the Herriott cell cavity. Fig.2-right depicts the measured spectrums after the MPC when the input power is limited to 1W (black) and when it reaches 123 W (red). A spectral content down to the -20 dB level is generated in the span from 980 to 1080 nm (red). The nonlinear interaction within a long free-space propagation provides a significant spectral broadening. From this spectrum, the Fourier transform limit (FTL) duration is ~ 34 fs, i.e. a pulse post-compression by a factor of ~ 10 .

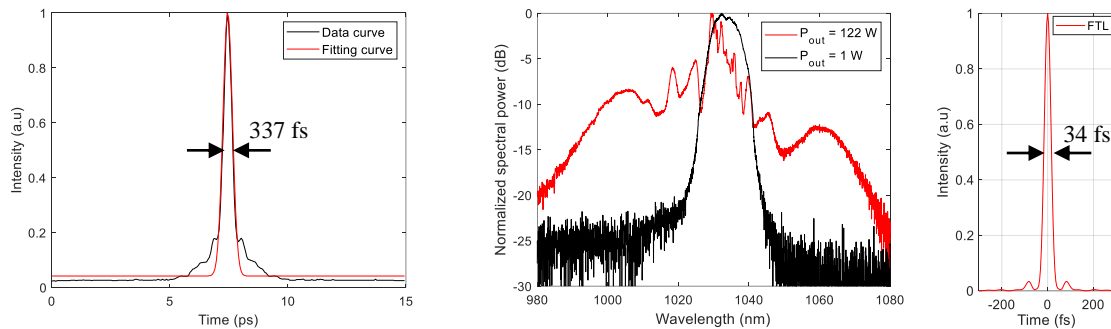


Fig. 2: Left: Autocorrelation trace of the compressed output combined beam. Center: measured spectrum after the MPC (red). Right: Fourier transform limit (FTL) of the spectrum.

We also studied the propagation of a linearly polarized Laguerre-Gaussian beam generated by the CBC digital laser (composite helical phase distribution applied on 61-beams) through the MPC. As illustrated on Fig. 3, the donut intensity distribution is rather well conserved after 17 round-trips within the Herriot cavity (B) up to the exit (C).

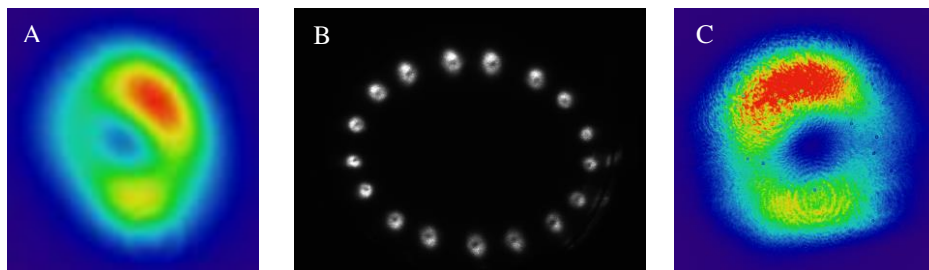


Fig. 3: MPC input LG beam (A); Beam pattern on the MPC back mirror, with 17 donut-spots according to 34 passes through the focus (B) and MPC output LG beam (C).

3. Conclusion and outlooks

First results from a CBC digital laser on spectrum broadening and beam quality conservation through MPC are presented. Results on post compression down to a few tens of fs and the implementation of a second MPC already delivered by n2-Photonics will be presented at the conference. Stacked the two MPC stages in cascade shall allow us to reach ~ 10 fs pulses with preserved donut shape as required for the NanoXCAN project.

This work received funding from the European Innovation Council (Open grant No. 101047223-NanoXCAN).

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