



**HAL**  
open science

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

Ihsan Fsaifes, Claude-Alban Ranély-Vergé-Dépré, Rezki Bechecker, Kilian Fritsch, Oleg Pronin, Jean-Christophe Chanteloup

► **To cite this version:**

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

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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

Ihsan FSAIFES<sup>1,\*</sup>, Claude-Alban RANÉLY-VERGÉ-DÉPRÉ<sup>1,2</sup>, Rezki BECHEKER<sup>1</sup>,  
Kilian FRITSCH<sup>3</sup>, Oleg PRONIN<sup>3</sup>, and Jean-Christophe CHANTELOUP<sup>1</sup>

<sup>1</sup> LULI, CNRS, École Polytechnique, CEA, Sorbonne Université, Institut Polytechnique de Paris, 91120 Palaiseau, France

<sup>2</sup> Thales LAS France SAS, 2 avenue Gay Lussac, 78995 Elancourt, France

<sup>3</sup> n2-Photonics, Hans-Henny-Jahn-Weg 53, 22085 Hamburg, Germany

\* ihsan.fsaifes@polytechnique.edu

**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  $\sim 3$  rad. The CBC is achieved when focusing the composite pupil with a single lens. The phase stabilization (at  $\sim 1$  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).

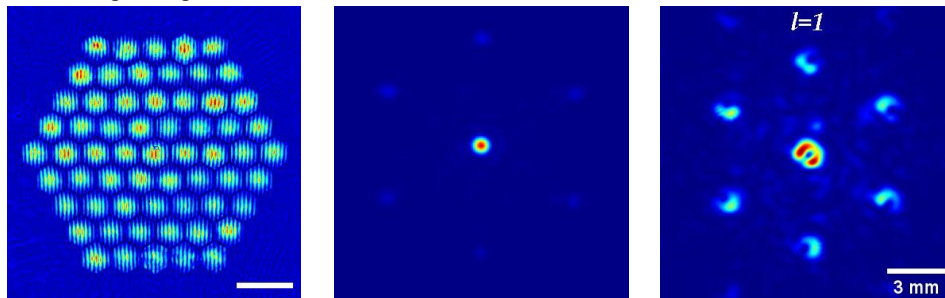


Fig. 1: Experimental near field interference pattern of 61 beamlets as operated on XCAN (Left). Experimental far fields with a flat phase (Center) and for an azimuthal order  $l = 1$  LG beam (Right).

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  $\sim 34$  fs, i.e. a pulse post-compression by a factor of  $\sim 10$ .

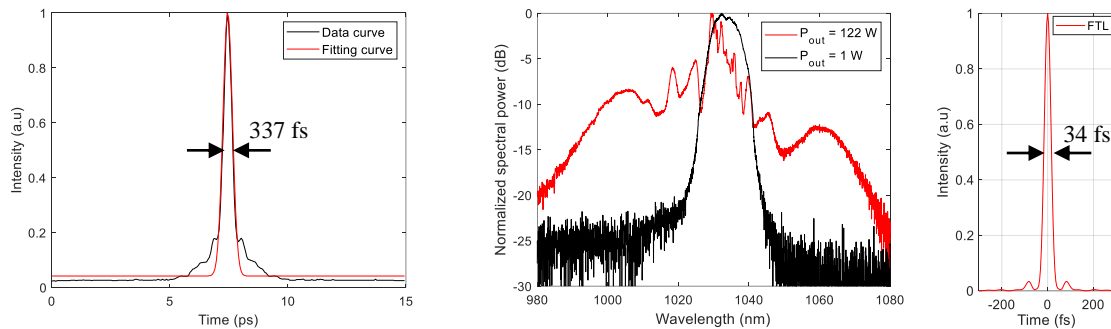


Fig. 2: Left: Autocorrelation trace of the compressed output combined beam. Center: measured spectrum after the MPC (red). Right: Fourier transform limit (FTL) of the spectrum.

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).

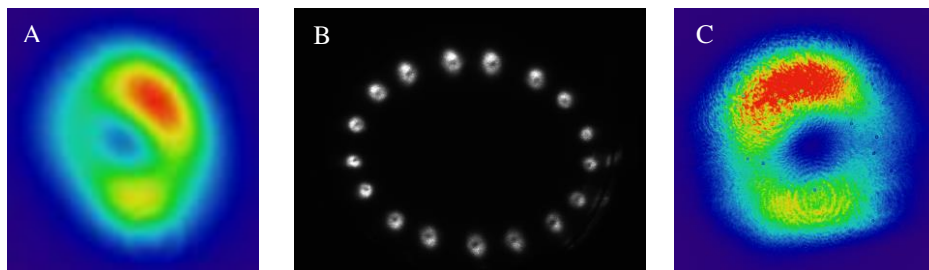


Fig. 3: MPC input LG beam (A); Beam pattern on the MPC back mirror, with 17 donut-spots according to 34 passes through the focus (B) and MPC output LG beam (C).

### 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  $\sim 10$  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).

- [1] F. Krausz, G. Korn, P. Corkum, I.-A. Walmsley, (eds.) *Ultrafast Optics IV*, Springer New York, NY, (2004).
- [2] M. Veinhard et al., "Orbital angular momentum beams generation from 61 channels coherent beam combining femtosecond digital laser", *Opt. Lett.* 46(1), 25-28 (2021).
- [3] I. Fsaïfes, C.-A. Ranély-Vergé-Dépré, M. Veinhard, S. Bellanger, and J.-C. Chanteloup, "Far field energy distribution control using a coherent beam combining femtosecond digital laser," *Opt. Express* 31, 8217-8225 (2023).
- [4] L. Turquet, X. Zang, J.-P. Kakko, H. Lipsanen, G. Bautista, and M. Kauranen, "Demonstration of longitudinally polarized optical needles," *Opt. Express* 26, 27572-27584 (2018).
- [5] K. Fritsch, M. Poetzlberger, V. Pervak, J. Brons, and O. Pronin, "All-solid-state multipass spectral broadening to sub-20 fs," *Opt. Lett.* 43, 4643-4646 (2018).