Programmable Orbital Angular Momentum beam generated from a 61 channels Coherent Beam Combining femtosecond laser

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Abstract: A 61 beamlets Coherent Beam Combination laser is used as a programmable phase source to generate high power Orbital Angular Momentum beams and open the path for higher order non-symmetrical user-defined far field distributions.

Application fields of Orbital Angular Momentum (OAM) laser beams keeps extending, ranging from selective trapping of particles [1], microbunching instability reduction in free-electron laser setups [2] to fluids flow characterization [3]. Traditional methods to generate such beams generally rely on laser cavity tuning [4] or Spatial-Light Modulators (SLMs) [5]. The first one offers high output powers but lacks of tunability, as a different cavity design must be engineered for each specific transverse beam distribution. The second method offers high tunability but is limited in output power by the SLM optical damage threshold. A more versatile alternative approach, potentially offering both high output power and tunability, is based on Coherent Beam Combination (CBC) of numerous beamlines [6]. We demonstrate the generation of AOM beams with the XCAN CBC prototype [7] where an array of 61 honeycomb distributed fibers allows a high-resolution phase control (figure 1).

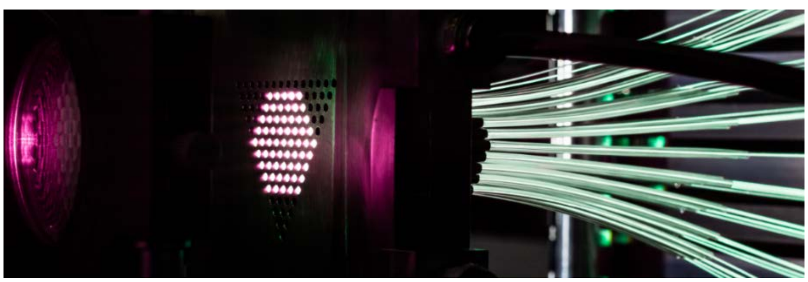


Fig. 1. XCAN laser head (center), collimating microlens array (left) and 61 Yb:doped fiber bundle (right).

This laser carries a high potential for greatly broadening the field of applications of structured light far beyond AOM centrosymmetric beams only. It indeed associates high peak (fs regime operation) and average (kW range) powers thanks to its diode-pumped Yb-doped fiber amplifying chain architecture. Scalable by nature, it has been studied to be compatible with up to 10,000 channels [8] paving the way to high resolution transverse amplitude and phase laser beam control. Hundreds to thousands of control points within the pupil would allow arbitrary shaped phase and amplitude distribution (not limited to cylindrical symmetries like for AOM) to be implemented through iterative electric field computing with Gerchberg-Saxton algorithm [9] for instance. Finally, this electric field control can be adjusted in real time (up to the kHz regime at the moment) offering an extra degree of freedom for applications requesting dynamic energy or power distribution control (drilling, cutting or soldering of material for instance).

The XCAN laser setup [7, 10] relies on 61 individually amplified and coherently combined beamlets, the phase of each being controlled in real time (kHz) via the combined used of variable optical delay lines, piezo-mechanical fiber stretchers, an interferometric phase measurement and a Stochastic Parallel Gradient Descent (SPGD) algorithm. Individual amplitudes can be adjusted through amplifier gain control.

The XCAN laser is then used to generate “61 pixels” l^{th}-order OAM beams phases expressed as:

$\varphi(x,y) = l.\tan^{-1}[(y-y_0)/(x-x_0)]$, where $l \in \mathbb{Z}$ is the topological charge number, (x,y) the beamlets position relative to the central beamlet position (x_0,y_0) at which the phase exhibits a singularity and amplitude is set to zero.

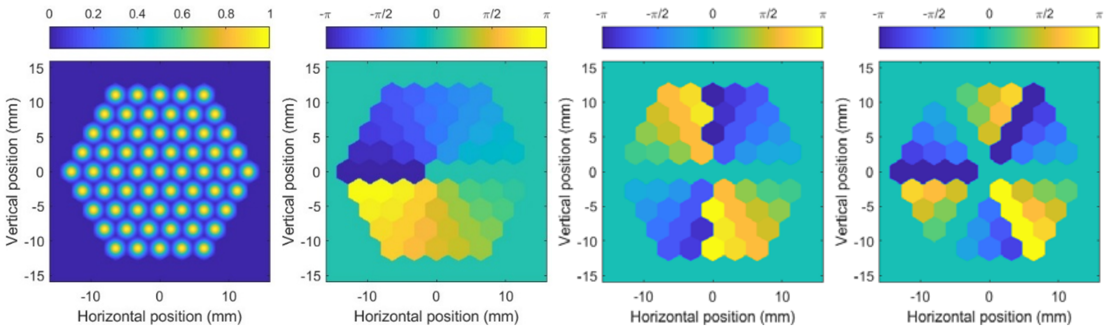
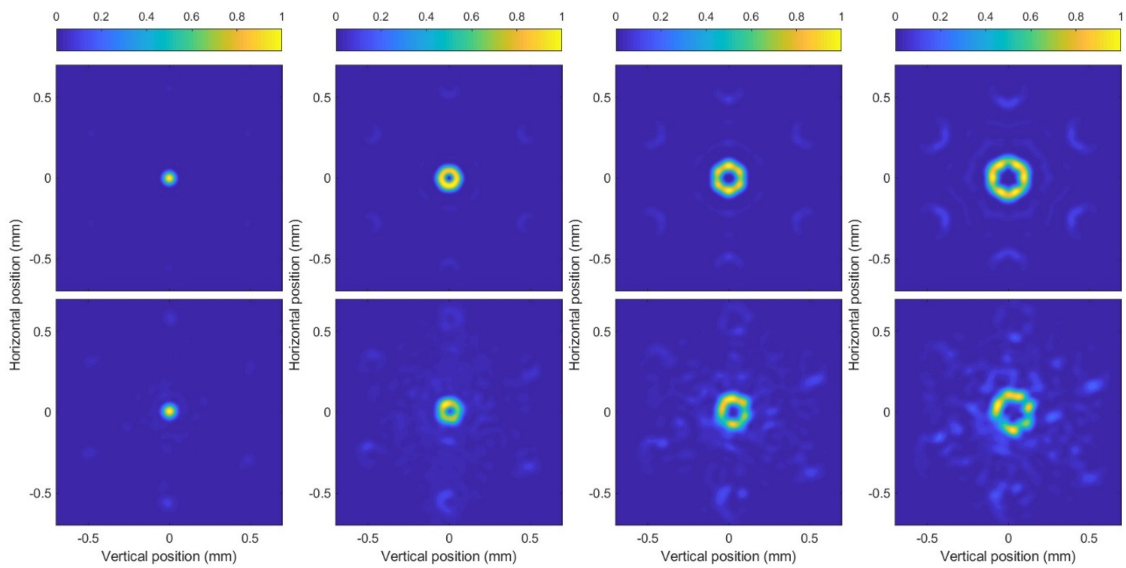


Fig. 2. Computed XCAN nearfield (left) and phase distributions for l = 1 & 2 (center) and l =3 (right) unwrapped over [–π;π].

Fig. 2 displays numerical simulation of XCAN nearfield (amplitude, left) and phase profiles for l =1, 2 and 3 (second to fourth positions) corresponding far fields shown in Fig 3 (top images) where they are compared to recorded experimental results (bottom images). Both numeric and experimental far fields corresponding to no-phase shift (*e.g.* $l = 0$) are displayed in left.



$l = 0$ $l = 1$ $l = 2$ $l = 3$

Fig. 3. Simulated (top) and experimental (bottom) far fields for different azimuthal index $l = 0$ to 3.

These results reveals a good agreement between both simulated and experimental far fields for each azimuthal index. The experimental measurements were recorded at 55 MHz, 10W average power. Further developments will include high average power operation (several 100 Watts), and generation of non-centrosymmetric far field distributions.

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