Title
Final Review Paper

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Publication Date
2023-12-11

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ABSTRACT
This review explores an article showcasing an innovative laser architecture using structured photonics for versatile light control. We focus our review on the included coherent beam combination, cylindrically structured pulses, and adaptable asymmetric pulses.

INTRODUCTION
Emphasizing the significance of structured photonics, the article discusses possible applications such as traditional optical communication, sensing, or more unconventional domains like particle and quantum physics. The article introduces an innovative laser architecture taking advantage of structured photonics. Specifically, this architecture makes use of coherent beam combination, offering integrated spatio-temporal field control and programmability. This architecture unlocks the potential for generating light with adaptable structures, utilizing increased degrees of freedom like amplitude, linear, spin angular, and orbital angular momenta. These degrees of freedom are currently often bottlenecked in existing technologies, and finding new avenues to use more of these is an important part of researching structured photonics.

The paper presents a proof of concept utilizing various degrees of freedom in light, including amplitude, linear, spin angular, and orbital angular momenta. It features seven fiber-based beamlines split from a femtosecond mode-locked laser. This demonstration also shows the architecture's ability to create programmable laser pulses, either as free-space synthesized light bullets or as an array of distributed coherent beamlines.

To be a bit more specific, the architecture uses phased arrays with individually controllable field-amplitude, carrier-envelope phase, relative phase, and polarization, enabling the synthesis of complex spatio-temporal wavevector distributions. It is also capable of free-space synthesis, showcasing the generation of various pulses in the far-field by combining amplitude and relative phase of the beamlines. Examples of this include conventional coherently combined beams, structured pulse synthesis, and cylindrically asymmetric pulses. The adaptive evolution of phase-fronts is illustrated, facilitated by Carrier-Envelope Phase (CEP) and relative Lock-in Optical Coherence Control (LOCSET) phase control.

The article concludes with some methods and technical information covering the experimental setup, carrier-envelope phase stabilization, beamline controls, multi-channel phase modulation using FPGA-based LOCSET, beam propagation model, and polarization vector map calculations.

METHODS
The paper both discusses and heavily relies upon pulse synthesis demonstrations, and I wanted to perform further research on this. The paper mentions three different types of synthesized pulses: conventionally coherently combined beams, cylindrically structured pulses, and asymmetric pulses.

Starting with conventionally coherent beams. In a coherent combination, the goal is to control the phase or amplitude of different beams in order for them to interact constructively. Coherent combination enhances the overall intensity of the output beam, providing a means to scale up the power while preserving the coherence properties of the individual beams.

In an ideal setting, we can see that the intensity profile of the combined beam result of CBC is shown in equation 1, the F{} refers to the fourier transform of the included portion of the equation.

$$I(r,z=L)=|\frac{exp(i(\frac{k}{2L})r^2)}{i\lambda L}F\{E(p,z=0)exp(i\frac{k}{2}\frac{1}{L-\frac{1}{f}}p^2)\}|^2 \tag{1}$$

Where electric field of an N-element linearly polarized fundamental mode Gaussian beam array at the source plane,

$$E(p,z=0)=\sum_{j=1}^{N}A_0*exp(-\frac{(p-p_j)^2}{w_0^2})\times circ(\frac{|p-p_j|}{\frac{d}{2}})exp(i\phi_j) \tag{2}$$

A_0 is the amplitude, ω_0 is the waist width, ϕ_j and d are the initial phase and aperture diameter of the jth beamlet respectively.[2] And we know that the intensity of a laser is just the amount of power per unit area. So our intensity is directly proportional to the power of the beam, but intensity is often a preferred metric as it accounts for the precise control of the power

The ability to coherently combine beams is particularly valuable in applications requiring intensity scaling. This technique avoids limitations that using a single amplifier on a single beam would exhibit, such as thermal lensing, transverse mode instability, and nonlinear effects like self-phase modulation. The next obvious question is what is the limitation of CBC? One of the key limitations lies in the combining efficiency of the beams. The most simple way of looking at this efficiency is equation 3 where we simply are taking the power measures at the output vs how much power goes in.[2,3,5]

$$\eta=\frac{P_{out}}{P_{in}}*100 \tag{3}$$

Next let's look at cylindrical structured pulse synthesis, this is a specific type of coherent beam combination where the resulting pulses exhibit a cylindrical symmetry in their phase distribution. The demonstrations involve manipulating the phases of the individual beamlines to create cylindrically structured pulses with alternating or gradually varying phase distributions.

A discretized first-order orbital angular momentum (OAM) beam is achieved using cylindrical structured pulse synthesis, where the phase of the synthesized pulses is defined in a way that spans a discrete range of values, akin to quantized angular momentum states.

This beam can be used to model a quantized version of the Laguerre-Guassian (LG) beam. Beams like LG beams have been heavily studied because of their helical wavefronts which have been shown to carry OAM.[14] Beams with OAM are of particular interest for their use in optical communication, because OAM states could be used as different carriers for multiplexing and transmitting multiple data streams, thereby potentially increasing the system capacity.[15] A typical LG beam can be described as in equation 4, where r is radius, ϕ is azimuthal angle, and z is propagation direction.[16]

$$u(r,\phi,z)=E_0\left[\frac{r\sqrt{2}}{w(z)}\right]^l L_m^l\left(\frac{2r^2}{w^2(z)}\right)\frac{\omega_0}{w(z)}\exp\left[-i\phi_{ml}(z)\right]\exp\left[i\frac{k_0r^2}{2q(z)}\right]\exp(il\phi) \tag{4}$$

And,

$$w(z)=w_0\left[\frac{(z^2+z_R^2)}{z_R^2}\right]^{1/2} \tag{5}$$

Finally to look at asymmetric pulses, the paper explores the generation of pulses with non-uniform or asymmetrical features, showcasing configurations that lead to abrupt phase transitions with reflectional symmetry.

The flexibility of the laser architecture in producing dynamic field singularities is emphasized in this context. A dynamic field singularity refers to a point or region in the optical field where certain properties, such as intensity or phase, exhibit abrupt changes or unique characteristics. The laser architecture's ability to dynamically manipulate the phases of individual beamlines allows for the creation of asymmetric pulses with varying and adaptable field singularities.

RESULTS AND INTERPRETATION

CBC is important because high-power ultrafast lasers are demanded for industrial-scale precision materials processing, e.g., in solar cell and lithium battery production.[1] Looking at state of the art technologies, a power output of 10.4kW with combining efficiency of 96% in a system with a 1:12 splitter has recently been demonstrated (2020), and currently is one of the leading and most impressive displays of coherent beam amplification.[1] We can test eq. 3 to check their efficiency value, given that they list the average power through the beam fibers as 896 W. Then the total power going into the beam combiner will be 12 * 892 or 10752 W. Now, 10752 divided by 10400 then multiplied by 100 will be ~96% efficiency which is the same as their claim.

When looking at both symmetric and asymmetric cylindrical pulse synthesis I was most interested in the OAM beam that displayed a vertex wavefront and then the next step of an LG beam. In Fig. 1 I show the results of using a beam modeling method[12,13] I modeled a discretized OAM beam (row a), then an asymmetric beam with opposite phase initializations (row b) to see if, in simple terms, two OAM phase setups would cancel each other out, and a simple LG beam (row c). As we can see from the wavefront, having the opposite hexagonal arrangements in the outer layer and inner layer destroys the donut behavior of the center, and the vortex of the phase is essentially ruined as well as expected from having an asymmetrical pulse synthesis.

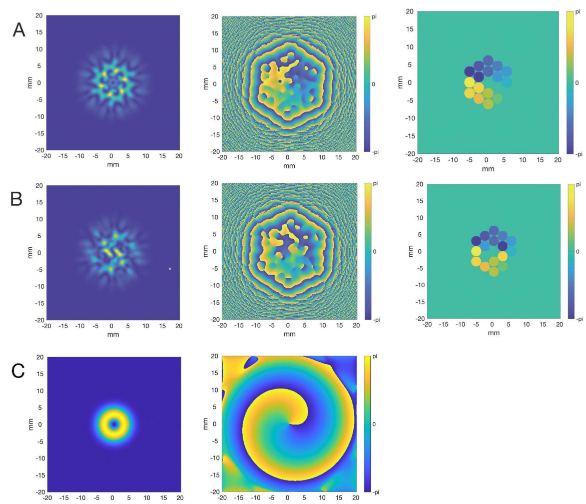

Fig. 1 Wavefront, phase distribution, and near field phase of OAM beam in row a, asymmetric beam in row b, and LG beam in row c

With the ever-growing interest and research into OAM beams for the use of optical communications among other applications, it's always good to consider all methods, and this discretized beam shows strong OAM and vortexing in the phase front and intensity distributions. As mentioned in the original paper, they found the MSE between the intensity distributions of an ideal and discretized OAM first order beam was as low as .0006.

CONCLUSIONS

In conclusion, the paper offered an innovative solution to taking advantage of the many degrees of freedom in structured photonics that current technologies often can’t due to bottlenecking. There is specifically a high amount of flexibility and possibilities when we consider the different kinds of pulse synthesis the system can exhibit just from the early proof of concept. Pulse synthesis offers solutions to many areas of need for photonics, whether it’s power output, OAM for communication, imaging, or unique field singularities among many more. This is why it is an important field of research, and fully exploring new innovative technologies is key.

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