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Abstract: Structured photonics offers a large degree of flexibility in the generation of field distributions through several important parameters such as amplitude, polarization, and phase. In this article, we review a particular structured photonic device using several beamlines with individually manipulated field parameters arranged in a hexagonal pattern to generate a specific field intensity distribution and extend the principle to higher order modes and analyze a possible implementations of polarization manipulation.

INTRODUCTION

Light possesses many characteristic properties that allow for engineering customizable spatial and temporal field distributions, such as amplitude, polarization, and phase. Modifying these parameters allows for virtually infinite possibilities for customizing the structure and topology of light. Structured photonics has many applications in fields such as molecular physics, optical communications, and particle physics, thus being able to engineer the structure of light is foundational to developing new technologies.

METHODS

In a report by R. Lemons, et al[1], a laser architecture enabled the programmability and design of light bullets, which can propagate with negligible diffraction distortion. The architecture used a phased array of individually controlled fibers, referred to as beamlines, arranged in a hexagonal pattern. The beamlines originated from a single femtosecond laser in the C-band wavelength range and pass through a 1:N beam splitter. One beam serves as a reference and all other beamlines are phased-locked to that reference phase and can be define as any arbitrary phase relationship. A conceptual overview of the laser architecture is shown in Figure 1.

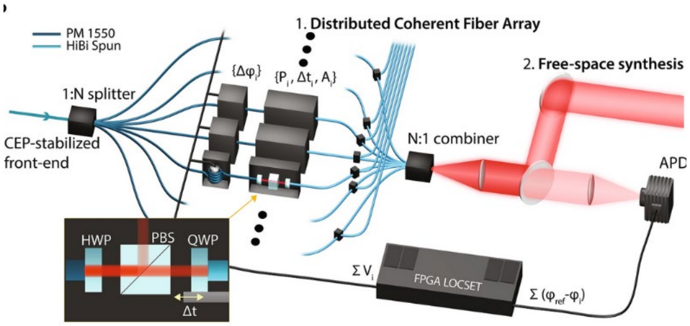

Fig. 1. Conceptual design of composable laser architecture, using a phase array of individually controlled beamlines originated from a single laser. (Ref. [1], Fig. 1b).

An FPGA assists in the modulation of each beamline through a piezoelectric transducer in the form of a fiber stretcher (by definition[2], acousto-optic phase modulation). In addition to modulating phase $\Delta\varphi_i$ with fiber stretchers, the amplitude A_i, polarization $\wp_i$, and timing Δt_i are manipulated by a half waveplate, polarizing beam splitter, a quarter wave plate, and a delay stage. Both waveplates allow for changes in the wave polarization, as the quarter wave plate can transform a linearly polarized beam into a circularly polarized beam while a half wave plate can rotate any polarization to any angle by changing the angle of incidence of the beam with respect to an optical axis. The delay stage controls timing Δt_i while the polarizing beam splitter modifies both polarization and amplitude. Each beamline is coupler into circularly birefringent fibers to preserve the beamline's polarization state, as circularly birefringent materials have different refractive indices for left and right circularly polarized light, respectively. Lastly, the beamlines are arranged, collimated, and synthesized in a N:1 combiner before being detected by an avalanche photodiode.

RESULTS AND INTERPRETATION

The report by R. Lemons, et al[1], demonstrated the synthesis of Laguerre-Gauss and helical field intensity distributions by manipulating the field parameters of each individual beamline. In addition, this laser architecture allows for programmable composite phase-fronts to be generated and produce beams with spatially and temporally variant spin angular momentum distributions, or polarization topologies, as well as generate optical pistons with a broad range of delays from a few wavelengths to much longer delays than a single delay stage would allow. These composite beams also need not be focused on a single point as demonstrated with a photodiode in the experiment, but rather can allow for unguided, free space configurations, and is shown as an option in the conceptual diagram in Figure 1.

CONCLUSIONS

The methods and results presented in the report by R. Lemons, et al[1] offer a strong possible implementation and demonstration of a structured laser architecture. The laser architecture presented allows for virtually infinite transverse field configurations through the manipulation of the amplitude, polarization, phase, and timing of the beam. In addition, the overall architecture presented allows for further expansion, as was discussed with the generation of different polarization topographies and the modeling of the usage of increased numbers of discrete beamlines. Further research is required in developing more systems that utilize more than seven discrete beamlines, and will highly depend on the exact application the structured laser would be used in. For instance, applications that would require a beam that is closer to an ideal case, such as a circular intensity distribution, would clearly require more discrete beamlines.

Another potential application for using additional beamlines would be the capability to generate higher-order Laguerre-Guassian or Hermite-Guassian modes. For instance, only the TEM_{03} Laguerre-Guassian mode would be possible with the laser architecture presented. Clearly, additional fiber beamlines would allow for the generation of more complex transverse field distributions that take the form of higher order Laguerre-Guassian modes assuming that the beamlines are arranged in a roughly hexagonal pattern. Hermite-Guassian modes could be generated in a similar fashion to the Laguerre-Guassian modes and would only require that the beamlines are arranged in a rectilinear pattern rather than a hexagonal pattern. These modes have field distributions given by

$$\hat{\varepsilon}_{mn}(x,y,z) = \frac{C_{mn}}{w(z)} H_m\left[\frac{\sqrt{2}x}{w(z)}\right] H_n\left[\frac{\sqrt{2}y}{w(z)}\right] \exp\left[-\frac{x^2+y^2}{w^2(z)}\right] \exp\left[i\frac{k}{2}\frac{x^2+y^2}{\mathcal{R}(z)}\right] \exp[i\zeta_{mn}(z)] \quad \text{(Eq. 1)}$$

where C_{mn} defines a normalization constant, H_m is the Hermite polynomial, w is the beam width, and $\mathcal{R}(z)$ is the radius of curvature of the beam as it propagates along z [2]. Higher order Hermite-Guassian modes could then be generated using additional beamlines in the same manner as would be done for higher order Laguerre-Guassian modes. These field distributions could then be used to carry modulated signals through free space as the intensity distribution pattern of Guassian modes does not change as the wave propagates.

REFERENCES

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