Femtosecond Filament Coupled with Structured Light for Free Space Optical Communication

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Abstract: We created a 4-bit communication channel for free-space optical communication (FSO) through a segmented space division multiplexing method using structured light coupled with a femtosecond-laser induced filament.

Introduction

First developed in 1880, free-space optical communications (FSO) is a powerful tool to transfer information through air [1]. However, due to its disadvantages and difficulties compared to fiber-optic communication (e.g. requires a clear line of sight), not until recently has interest in FSO resurfaced [2]. Weather conditions especially cloudy and foggy conditions will significantly attenuate light to the point where no signal is recoverable at the detectors. One promising scheme to tackle the issue is the utilization of filamentation [3]. Filamentation is a phenomenon describing a long thin plasma channel (the filament), produced by the balance between the optical Kerr effect and plasma defocusing [4]. Properties of filaments such as their stability under air turbulence [5] and their interaction with water droplets [6] have been studied. Jean-Pierre Wolf et al. showed that a quasi-static transparent channel is created around the filament through the fog by using a high repetition rate laser (>500 Hz) [3]. However directly coupling a beam of light with the filament introduces detrimental effects to the information signal. We are proposing a signal that is coupled around the filament, using structured light Fig.1. Different structured light beams including Laguerre-Gaussian (LG) and Gaussian Array are tested in order to identify the strongest candidate to utilize the quasi-static transparent channel around the filament. Furthermore, the LG beam was utilized to demonstrate a 4-bit Segmented Space Division Multiplexing (SSDM) scheme. The SSDM scheme showed minimal crosstalk between channels while significantly increasing the data capacity of the system.

Result and Discussion

The phase singularity in the center of the vortex beam, along the propagation axis, ensures no light is directly interacting with the filament. The spatial profile of the beam and the immunity to diffractive spreading should
allow it to effectively work in the quasi-transparent channel. The femtosecond beam attenuated by several orders of magnitude after the filament by a series of filters, is shown in Fig. 2—(a). In Fig. 2—(b) the LG beam (with topological charge $\ell = 12$) is shown. The LG beam is produced by illuminating a phase-only spatial light modulator (SLM) displaying the corresponding phase mask [7]. In this instance, the femtosecond beam is blocked to image just the LG beam. We vary the inner diameter of the annular beam between $7.6 - 10$ mm, using a beam expander. The lower bound for the inner diameter is limited by the dimensions of the hole in the in-house developed mirror coupler Fig.1—(b). This beam is then coupled with the filament as shown in Fig. 2—(c). The LG beam does not interact with the filament for the range of diameters mentioned above. The basic principle of Segmented Space Division Multiplexing (SSDM) using an annular beam is shown in Fig. 2—(d). The beam is divided into 4 quadrants, each representing a bit. Since the LG beam is fully controlled by the phase mask on the SLM, each quadrant can be controlled by manipulating the phase mask. The middle of each quadrant is selected as the detection zone to maximize the efficiency of the scheme. This scheme is difficult to implement using a single Gaussian beam, due to dispersion characteristics of the beam leading to crosstalk between bits. Furthermore, an array of Gaussian beams is generated. As shown by Fig. 2—(g) & (h), 4 separate Gaussian beams are arranged in a square. Like LG beams, the Gaussian array can also be used in the SSDM scheme. Each bit represented by a beam can be individually controlled via the SLM and specific phase masks similar to the LG beam. In this way the Gaussian array can form a n-bit SSDM communications system.

Conclusion

We have experimentally demonstrated a novel and robust scheme for FSO by coupling a filament with structured light. Different beams were tested and the Laguerre-Gaussian beam was selected as it demonstrated minimal dispersion, easy of use, and significantly improved signal to noise ratio. We also demonstrated through SSDM a novel approach to increase the capacity to a 4-bit multiplexed communications channel. The scalability of this system expands the potential of FSO systems to work at much higher capacities than current solutions. The data shows minimal crosstalk between each bit, showcasing the potential for using filamentation and annular beams for free space optical communication.

References

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