Optical Trapping and Manipulation of Multiple Microparticles Using SDM Fibers

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Abstract: We demonstrate optical trapping and dynamic manipulation of microparticles using multicore and few-mode fibers. Tuning of the input state of polarization of the trapping beam allows for particle rotation and adjustable trapping distances. © 2018 The Author(s)

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1. Introduction

Manipulation of particles at the micro and nanometric sizes has become an important requirement for research in diverse fields such as physics, chemistry, biology, and biomedical sciences [1]. The preferred method for non-contact trapping and manipulation is based on the use optical forces. A wide variety of approaches capable to generate and dynamically adjust specific light patterns to trap multiple particles have been demonstrated [2]. However, the techniques to manipulate trapped particles usually rely on optical setups involving complex alignment processes resulting in bulky arrangements. A simple approach to achieve optical trapping entails the use of optical fibers, reducing the complexity and size of the optical arrangements for trapping and manipulation. Nevertheless, trapping of multiple particles using optical fiber based techniques typically requires elaborated setups and/or devices involving complicated fabrication procedures [3,4].

Current research in optical communications has focused on the development of new optical fiber technologies seeking to increase the amount of information transmitted through a single fiber. This has driven to explore the spatial domain in optical fibers [5], leading to technologies involving multicore fibers (MCFs) and few-mode fibers (FMFs), providing a means to generate on-demand multimode signals [5]. Complementary to these technologies, the development of spatial multiplexers, such as photonic lanterns, allows to selectively exciting individual LP modes in optical fibers [6,7]. In this paper, we present a new approach for microparticle trapping using optical fibers for space-division multiplexing. In particular, we demonstrate that MCFs and FMFs can be used to generate dynamically adjustable modal patterns useful for trapping and manipulation of multiple microparticles.

2. Experiments

Optical trapping was performed by selectively generating different light patterns at the output of either a MCF or a FMF using the experimental setup shown in Figure 1a. Control of the generated patterns was achieved through adjustments in the state of polarization (SOP) of the signal launched into each fiber under test (FUT). For this purpose, a laser diode (LD, = 1550 nm) was coupled to a fiber-optic polarization synthesizer (PSY-101, General Photonics) used to control the input polarization. The output end of the FUT was fixed to a XYZ -translation stage and placed inside a cuvette containing a solution with deionized water and dispersed microparticles. Two kinds of particles were used for the solutions: silica spheres (≈ 8 μm average diameter) and polystyrene spheres (≈ 4.8 μm average diameter).

Fig. 1. a) Experimental setup for optical trapping and manipulation. End facets and output mode profiles of the fibers: b) seven core (MCF) and c) few-mode (FMF) fiber.

Two different fibers were used in these experiments: a seven-core MCF (Fig. 1b) with 11 μm core diameters and with 2 μm core separation [8], and a 15 μm graded-index core FMF (Fig. 1c) supporting 2-LP modes. For light
coupling, the MCF was directly spliced to a standard single-mode fiber (SMF-28), whereas the FMF was spliced to the multimode output of an all-fiber mode-selective photonic lantern (PL) capable to generate 2 LP fiber modes [7].

3. Results

Particle trapping was first achieved with a fixed SOP input signals and with optical powers from 60 - 200 mW and 6 - 40 mW for the MCF and FMF, respectively. Multiple microparticles were successfully trapped at the locations with maximum intensity of the generated light patterns. Subsequently, the input light polarization was changed yielding a spatial redistribution of the intensity patterns, thus resulting in the displacement of the microparticles. These effects were observed for the two particle sizes and for each of the fibers.

When using the MCF (31 cm long), a series of patterns were generated due to the change in the coupling conditions among all the seven cores (see Fig. 1b) [8]. For this fiber, and for both types of microparticles, changing the SOP of the input signal produced controlled longitudinal displacement of each particle; hence, the trapping distance can be readily adjusted (see Figs. 2a and 2b). For abrupt changes in the light pattern, the microparticles can also swap positions among the different intensity maxima (Fig. 2c). For the FMF, the input signal was launched into the PL to excite a degenerate LP 11 mode in the FMF. This was then transmitted along 2 m of the FMF yielding two symmetric spots with similar intensities at the output end (see Fig.1c) allowing for trapping two silica microparticles. Rotations of the input SOP lead to rotation of the degenerate LP 11 mode, consequently producing rotation of the trapped microparticles (Fig. 2d). In comparison, a larger number of particles were trapped when using the smaller polystyrene spheres, owing to the mode effective areas at the output of the FMF (Fig. 2e).

![Image](image.png)

Fig. 2. Image sequences of microparticle trapping and manipulation. Adjustments in the input SOP launched in the MCF leads to longitudinal displacement of the microparticles: a) silica and b) polystyrene spheres, and c) trapping spot swapping. For the FMF, changes in the SOP lead to rotation of the d) silica and e) polystyrene spheres.

4. Summary

We have demonstrated optical trapping of multiple microparticles using fibers for spatial division multiplexing. These allow for the generation of light patterns that can be dynamically adjusted through changes in the SOP of the input signal. Using a multicore fiber allowed for changing the trapping distance of each microparticle, as well as for swapping the microparticle positions among the maxima of the light pattern. Finally, the use of a few-mode fiber granted the rotation of a specific microparticle arrangement. These results represent a versatile and compact means for trapping and manipulation of multiple micron-sized objects by means of a single fiber, and may extend the applications of spatial multiplexing devices.

5. References