Micro-3D printed miniaturized systems for optical trapping and manipulation

Carlo Liberale

Biological and Environmental Sciences and Engineering (BESE) Division, King Abdullah University of Science and Technology (KAUST), Thuwal, 23955-6900 Saudi Arabia
Computer, Electrical and Mathematical Science and Engineering (CEMSE) Division, King Abdullah University of Science and Technology (KAUST), Thuwal, 23955-6900 Saudi Arabia

Abstract

Optical tweezers (OT) are non-destructive, contactless tools that use light to trap and manipulate microscopic objects. We design and fabricate miniaturized systems that provide new optical trapping and manipulation tools. Our work takes advantage of the design freedom, flexibility, and high resolution afforded by micro 3D printing based on two-photon lithography. In particular, we present a dynamic counterpropagating beam trapping scheme, exploiting two 3D printed right-angle prism mirrors, and a novel hybrid photonic structure to create fiber optical tweezers.

Keywords: Optical tweezers, Two-photon polymerization, Optical fibers

I Introduction

Optical tweezers (OT) are non-destructive, contactless tools that use light to trap and manipulate microscopic objects[1]. Since the first demonstration of an optical trap by Arthur Ashkin, they have found application in diverse fields, particularly in biomedicine and physics.

Here, I present our work on designing and fabricating miniaturized systems that integrate with optical microscopes and fiber optics, providing new tools for optical trapping and manipulation.

II Methods and results

1. Fabrication method

We use a commercial micro 3D printing system based on two-photon lithography (Nanoscribe), a cutting-edge fabrication method that offers 3D design freedom, flexibility, and high resolution. In this method, a near-infrared femtosecond laser is focused by a high-numerical-aperture (NA) objective, exploiting a two-photon absorption process to induce photopolymerization in a small focal volume. In our work, this fabrication approach allows the direct in-situ fabrication of miniaturized hybrid optical systems, realized in a single step, and including different photonic components such as micro-lenses, micro-reflectors, and waveguides with photonic crystal fiber designs[2].

2. Fiber optic tweezers

The miniaturization of OT using single optical fibers has attracted significant interest as it opens up new possibilities such as trapping in turbid media or in-vivo. Several groups demonstrated single-fiber OT, but the proposed approaches use non-standard fibers and grant limited design flexibility in controlling the optical trap geometry[3]. We present a novel 3D micro-printed hybrid photonic structure creating ultra-compact fiber tweezers with fully controllable optical parameters. The structure is made of stacked refractive, reflective, and waveguiding optical elements (see Fig. 1a) and is fabricated in a single step on the end-face of a single-mode fiber (Fig. 1b). The design of the different parts of the hybrid structure allows an easy and independent tuning of the trapping parameters as the NA and the working distance of the optical trap. We demonstrate the 3D trapping capabilities of the proposed fiber OT.

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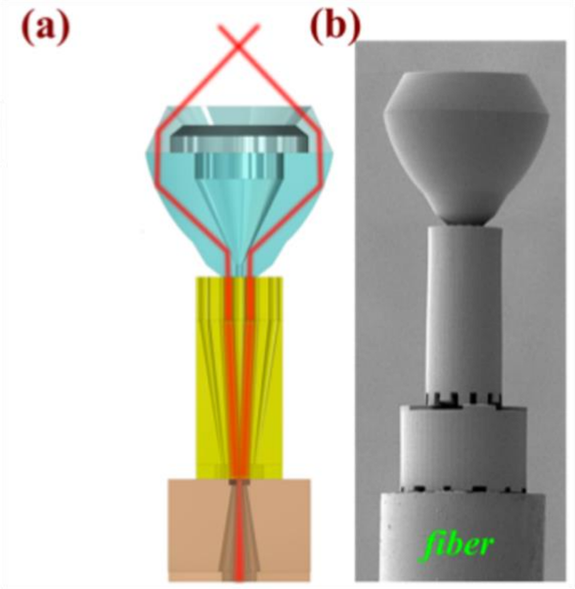

Figure 1. (a) Design of the fiber OT, (b) SEM image of the structure fabricated on the tip of the fiber.

3. Counterpropagating-beam optical tweezers

A setup based on counterpropagating beams focused by two facing lenses was the first configuration used by Arthur Ashkin to create an optical trap[4]. However, the difficulties in the alignment of the two beams have hindered the application of this trapping scheme until the fiber-based dual-beam laser trap was proposed[5]. This scheme simplified the optical setup by replacing the two lenses with two optical fibers and renewed the interest in counterpropagating beam traps as a tool for biophysical studies. Still, the alignment of fibers is time-consuming, not reconfigurable, and does not allow 3D manipulation of the sample. Here we show a dynamic counterpropagating beam trapping scheme (Fig. 2) that exploits two 3D printed right-angle prism mirrors, a single low-NA objective, and a Spatial Light Modulator (SLM). The SLM creates multiple beams that are redirected to face each other by reflection through the opposing mirrors. By changing the phase mask on the SLM, we can move the traps and manipulate in 3D the trapped sample. The key advantages of this approach are the simple alignment, the long working distance that allows trapping of large samples, the straightforward compatibility with other advanced microscopies, and the intrinsic side-view of the trapped object.

We demonstrate the viability of our approach by performing trapping and 3D optical manipulation of dielectric beads and cells.

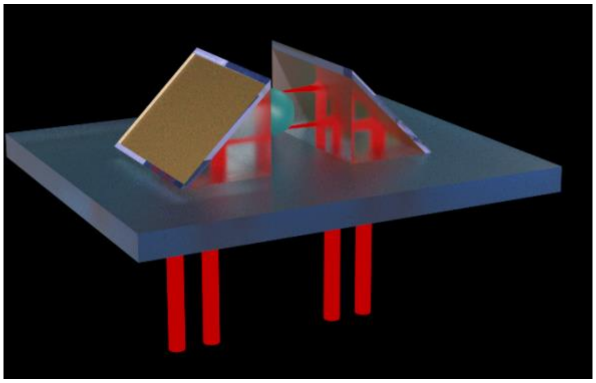

Figure 2. Sketch of the counterpropagating-beam trapping configuration using the 3D printed micro-prisms. Here, two beam pairs are show to trap a spherical bead

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