Optics Communications 365 (2016) 103–107

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Single optical tweezers based on elliptical core fiber

Yu Zhang [a,b], Li Zhao [a], Yunhao Chen [a], Zhihai Liu [a,b,*], Yaxun Zhang [a], Enming Zhao [a], Jun Yang [a], Libo Yuan [a]

[a] Key Lab of In-fiber Integrated Optics, Ministry Education of China, Harbin Engineering University, Harbin, China
[b] Centre for Micro-Photonics Swinburne University of Technology, P.O. Box 218 Hawthorn, Vic 3122, Australia

ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form
24 November 2015
Accepted 29 November 2015
Available online 14 December 2015

Keywords:
Elliptical core optical fiber
Single optical fiber tweezers
Trap
LP_{11} mode

ABSTRACT

We propose and demonstrate a new single optical tweezers based on an elliptical core fiber, which can realize the trapped yeast cell rotation with a precise and simple control. Due to the elliptical shape of the fiber core, the LP_{11} mode beam can propagate stably. When we rotate the fiber tip, the LP_{11} mode beam will also rotate along with the fiber tip, which helps to realize the trapped micro-particle rotation. By using this method, we can easily realize the rotation of the trapped yeast cells, the rotating angle of the yeast cell is same as the elliptical core fiber tip.

1. Introduction

Since optical tweezers were first proposed by Ashkin in 1986 [1], optical tweezers have developed to be an effective tool to handle biological cells or organelles [2–7]. Besides that, the rotation manipulation of a trapped micro-particle is also very fascinating [8–10]. Traditional optical tweezers are typically created by tightly focusing laser beams with objective lens [11–12], but compared with the bulky structure and expensive cost of traditional optical tweezers, the optical fiber tweezers provide a more flexible solution towards miniaturized, integrated traps [13–15]. The early optical fiber tweezers are realized by multi optical fibers, using two or more optical fiber guiding light beams crossing propagating getting optical intensity gradient distribution to manipulate the micro-particle. However, multi fibers optical tweezers have their short comings, they need multi high precision micromanipulators to control multi optical fibers, which means that the cost of optical tweezers is also high and it is inconvenient. Although the following integrated methods [16,17] solve this problem, the fabrication of the integrated fibers is very complex. Then as the need for further, the single fiber optical tweezers turns out [18–24], which is more simple and practical to be a tool to be used in the research. Zhang [25] report a single fiber optical tweezers to rotate a yeast cell by rotating the output light field pattern distribution of the LP_{11} mode beam, which is realized by twisting the fiber. However the fiber twisting angle and the yeast cell rotating angle do not follow a strict liner relationship. The LP_{11} mode propagating in a normal single core fiber is not stable even with a tiny disturbance, so it's hard to control the fiber twisting angle to make the yeast cells rotate precisely. Therefore we need to find a more efficient way to manipulate and rotate the trapped yeast cells.

In this paper, we propose and demonstrate a novel elliptical core single fiber tweezers. When the LP_{11} mode is excited in the elliptical core fiber, the special structure of the elliptical shape fiber core can keep the LP_{11} mode distributing stably, the symmetry axis of two lobes being along the short axis of the elliptical core, which determines that the LP_{11} mode can propagate stably. Thus when we stretch or twist the elliptical core fiber, the pattern distribution of the LP_{11} mode will not change obviously. This property provides an advantage to rotate the yeast cells just by twisting the fiber. The fiber twisting angle and the yeast cell rotating angle is the same. This new elliptical core fiber tweezers has the characteristic of simple and low cost, which is feasible to be used in practical fields conveniently.

2. Elliptical core fiber tweezers probe

2.1. Elliptical core fiber tip

The panda core fiber (made in our laboratory) with an elliptical shape core and two air holes is used in our experiment. The cladding diameter of the elliptical core fiber(ECF) is 125 μm, the long axis diameter of the elliptical core is 17.5 μm, and the short

* Corresponding author at: Key Lab of In-fiber Integrated Optics, Ministry Education of China, Harbin Engineering University, Harbin, China.
E-mail address: zhihai@vip.sina.com (Z. Liu).

http://dx.doi.org/10.1016/j.optcom.2015.11.076
0030-4018/

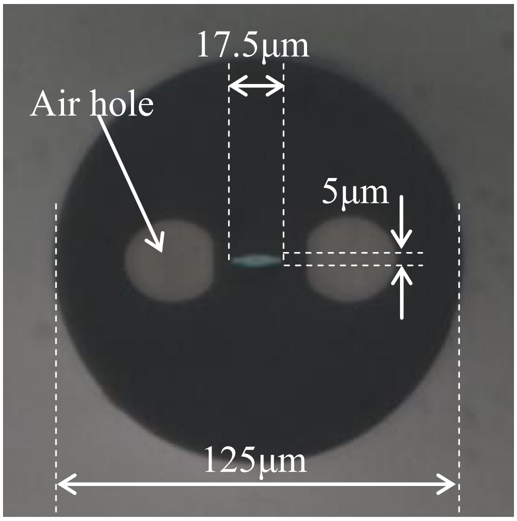

Fig. 1. The profile of the elliptical core fiber.

axis diameter is 5 μm. The cladding refractive index is 1.4668 and core refractive index is 1.4717. Fig. 1 shows the profile of the elliptical core fiber.

In order to obtain a large enough gradient distributed light intensity filed, we grind the fiber tip to be 34°. We employ the fiber grinding and polishing method to fabricate the fiber tip to be a wedged shape. The schematic diagram and the images of the fiber tip are shown in Fig. 2.

2.2. Theoretical analysis and simulations

We employ the COMSOL™ Multiphysics software to simulate and calculate the light field distribution of LP_{11} mode beam in the elliptical shape core, and the results are shown in the Fig. 3. According to the Fig. 3(a), when we choose the 980 nm wavelength light source, the LP_{11} mode beam will be excited and propagating stably. The symmetry axis of the LP_{11} mode beam two lobes is along with the short axis of the elliptical core. Fig. 3 (b) shows the experimental results of the LP_{11} mode beam light filed distribution. Simulation condition: light source wavelength is 980 nm; the refractive index of the elliptical core fiber cladding and core is 1.4668 and 1.4717, respectively. We can see that the LP_{11} mode exists well in the elliptical core fiber. When we stretch or twist the fiber in the experiment, the optical intensity of the LP_{11} mode two lobes will not change.

3. Optical force simulation and calculation

For the LP_{11} mode beam which propagates in a elliptical shape fiber core, we should calculate the transverse trapping force in *xoz* plane and *yoz* plane respectively. It is because that in the *yoz* plane, the transverse force generated from the LP_{11} mode beam is equivalent to the transverse force generated from the LP_{01} mode beam. Therefore we build two 2D simulated models by using the Rsoft™ FullWAVE software, and employ the FDTD (Finite Difference Time Domain) numerical algorithm to simulate and calculate the optical trapping force of the elliptical core single fiber tweezers in the *yoz* plane and *xoz* plane, respectively(see Fig. 4). The simulated condition are: the light source wavelength is 980 nm, the light source power is 1 mW; the diameter of fiber core in *xoz* plane is 17.5 μm, and the diameter of fiber core in *yoz* plane is 5 μm, and the diameter of the micro-particle is 4 μm and 10 μm. The refractive index of the fiber core, cladding, micro-particle and the surrounding medium (water) is 1.4717, 1.4668, 1.4 and 1.33 respectively. The grid step is chosen as 0.05 μm.

The negative values of the trapping forces indicate that the micro-particle will be pulled back to the fiber tip. Thus the positive values of the trapping forces indicate it will pushed the micro-particle away from the fiber tip. According to the Fig. 4(a), when

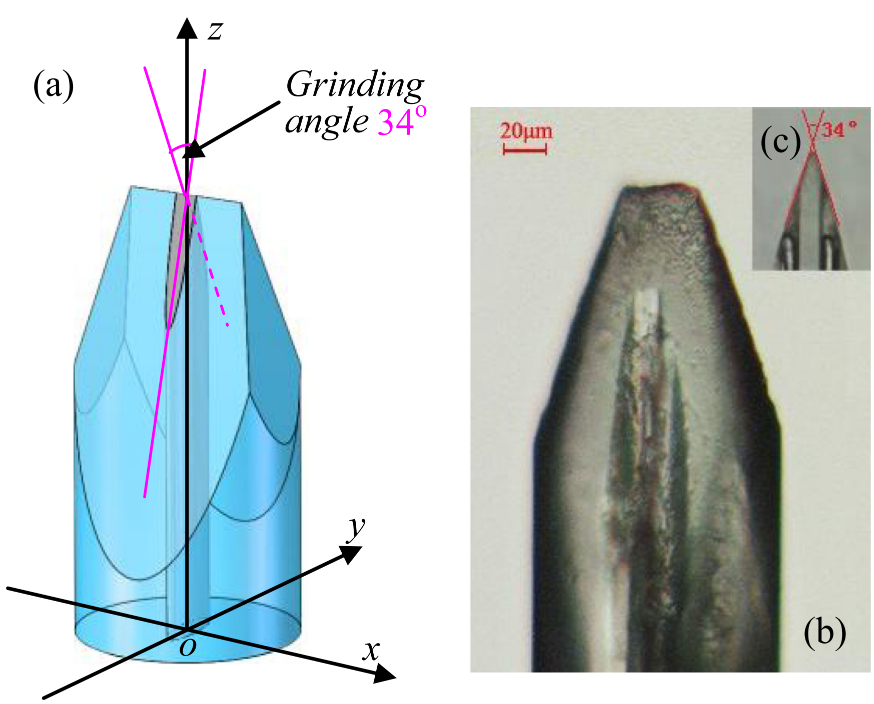

Fig. 2. (a) Schematic diagram of the wedged tip of the elliptical core fiber, here in order to see clearly, we omit the air holes in the schematic diagram. (b) Image of the fiber tip; (c) image of the fiber tip (seeing from *yoz* plane).