Two beams optical tweezers built by a two-core fiber

Libo Yuan*, Zhihai Liu, Jun Yang, Chunying Guan
Photonics Research Center, College of Science, Harbin Engineering University,
Harbin 150001, P. R. China

ABSTRACT

We present an abruptly tapered twin-core fiber optical tweezers, which is fabricated by fusing and drawing the twin-core fiber (TCF). The two beams guided by the TCF, and a larger converge angle between the two beams are made due to the abrupt tapered shape. The two beams converged at the micro-lensed tip, then forming a fast divergent optical field. The microscopic particle trapping performance of this special designed tapered TCF tip is investigated. The distribution of the optical field emerging from the tapered fiber tip is simulated based on the beam propagation method (BPM). By using this two-beam combined technique, a strong enough gradient forces well is obtained for microscopic particles trapping in three-dimensional. The abruptly tapered TCF optical tweezers is rigid and easy to handle, especially useful for build-up a multi-tweezers system for trapping and manipulating micro-scale particles.

Keywords: Optical tweezers, twin-core fiber, tapered fiber, laser trapping.

1. INTRODUCTION

Since first demonstrated by Ashkin in 19861,2, optical tweezers (a single-beam gradient force trap) technique has been developed in several directions. Examples are optical micro-machines and micro-components3-7, the extension of optical tweezers to multiple beam sites to create two-dimensional particle arrays8,9 as well as stacking of a small number of particles in standing-wave geometries10 and by using Bessel light beams11 to construct three-dimensional trapped structures12. In parallel with this, the optical tweezers technique has been widely used in biology, physics and chemistry. Especially in biology, it has been applied in researches on cells, viruses, bacteria and DNA molecules. Applications now range from the manipulation of the nano-particles to the assembly of the microstructures13. Usually a high N.A. microscope objective is necessary to focus the laser beam in the traditional optical tweezers. Despite the relevant results achieved in many fields, the bulky structure of the traditional optical tweezers still limits their utilization in several environments. In order to make the manipulation of the tool easier and more convenient, fiber optical tweezers has been developed since 199314. Using optical fibers to carry the light to a micro-object, in which it is to be trapped15,16, is much easier to handle, and much more suitable for practical use such as in trapping, levitating and rotating of the microscopic particles17-23. Usually, etching or drawing method24-26 was used to fabricate the standard single mode fiber tip for particle trapping in three-dimensional. Here we describe a means of implementing optical tweezers by using a twin-core fiber that extends the functionality of the fiber optical tweezers by allowing trapping with orientation, more like the real tweezers (tiny pair of tongs).

2. TWIN-CORE FIBER TIP

Unlike the polishing and chemical etching manufacture techniques, the twin-core fiber (TCF) optical tweezers was manufactured by heating and drawing the TCF to form an abruptly taper profile. At the tip of the tapered fiber, a small half spherical high numerical aperture micro-lens is automatically formed due to the surface tension of the fused quartz glass. Fig.1 shows the twin-core fiber and the tapered fiber probe (see Fig.1 (a) and (b)) used in our experiment, a yeast cell can be easily trapped and manipulated in water as shown in Fig.1 (c). In the abruptly tapered zone, the two beams coming from each core were guided in the tapered angle, and gradually transferred from the guide mode into the radiation modes due to the core diameter abruptly reduced near the fiber tip, as shown in Fig.2. The two radiation beams passing though the high numerical aperture micro-lens that focused on the two beams in a micro-scale space near the tapered TCF tip and formed a fast divergent-beam away from the fiber tip. By using this two-beam combined technique, a strong enough gradient forces potential well is obtained for micro-particles trapping in three-dimensional with the

* Email: lbyuan@vip.sina.com; Tel: +86-451-82519758; Fax: +86-451-82519850
orientation in the twin-core plane. The trapping force of this TCF based optical tweezers can be easily controlled by adjusting the input optical power.

(a) Cross-section of the TCF;  (b) Abrupt TCF probe;  (c) A yeast cell has been trapped at the fiber tip

Fig.1 Image of the twin-core tapered fiber optical tweezers manufactured by heating and drawing with an abruptly tapered profile tip for trapping small particles.

Fig.2 The abrupt twin-core fiber profile and the simulation result of BMP (beam propagation method).

3. EXPERIMENTAL SETUP

The TCF optical tweezers experiment setup and its working principle are described as Fig.3. A laser diode (LD) with wavelength at 980nm is used as the light source with its power to be tuned from 0 to 120 mW by adjusting the driving current of the LD.

Fig.3 Experiment set up and working principle of the TCF optical tweezers.
The pigtail fiber of the laser diode is single mode fiber. In order to launch the optical power into the TCF, we are heating and drawing the fiber at the splicing point after spliced the single mode single core fiber and the TCF, thus a couple zone between the single mode single core and twin-core single mode fiber is formed. By this way, the input power is coupled and shared in the two cores and guided the two beams to the TCF tapered end.

4. THEORETICAL SIMULATION RESULTS

Near the tip of the twin-core tapered fiber end, the intensity distribution of the output optical field is simulated by using the beam propagation method (BPM) 28. In the simulation, it is assumed that the TCF tapered probe emerged in the surrounding medium (say, water) with the refractive index 1.33, and the refractive indices of the TCF cladding and the fiber core are 1.452 and 1.463, respectively. The 3-dimensional finite difference BPM has been used to solve the Helmholtz equations. This method is exact up to the discretization error. The transverse grid sizes $\Delta x$, $\Delta y$ are 0.03$\mu$m and 0.03$\mu$m, respectively. The longitudinal step size $\Delta z$ is 0.5$\mu$m. The transparent boundary conditions were applied. The Gaussian incident field is launched into both fiber cores simultaneity and the wavelength is 0.98$\mu$m.

The abruptly tapered fiber profile can be described as

$$R(z) = \begin{cases} 
(R_0 - r_0) - (R_0 + r_0) \left[ \frac{\tanh[\nu(z - l_0/2)]}{\tanh(l/2)} \right], & 0 < z < l_0 - r_0 \\
\sqrt{r_0^2 - (z - l_0/2)^2}, & l_0 - r_0 \leq z \leq l_0 
\end{cases}$$

(1)

The numerical simulation parameters such as $R_0 = 62.5\mu$m; and the radius of half spherical micro-lens at the tapered fiber tip is $r_0 = 2.5\mu$m; tapered fiber length $l_0 = 200\mu$m; and the parameter $l = 288\mu$m, the tapered fiber profile parameter $\nu = 0.018(\mu$m$)^{-1}$, represents the shape changing characteristics. For the TCF, the distance between the two cores is 62.5$\mu$m, and the diameter of each core is 3.7$\mu$m. The simulation results of the output far-field intensity distribution are plotted in Fig. 4 at the plane perpendicular to Z direction. It is shown that the two beams are intercrossed inside of the TCF tip and separated outside of the fiber tip and the divergent angle is over 21 degrees.

![Computed Transverse Field Profile at Z=204 $\mu$m](image1)

![Normalized Intensity](image2)

Fig. 4 The far-field radiation intensity distribution at the tapered twin-core fiber tip (z=204$\mu$m).

5. CONCLUSIONS

In summary, the demonstrated twin-core fiber optical tweezers, together with the fabrication process, should lead to functionality extend in three-dimensional optical trapping, and made the optical tweezers easy control and conventional operating as tools for biology and micro-assembling.

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REFERENCES


