Trapping Power Improvement of Twin-Core Fiber Optical Tweezers

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***Abstract*— Far field distribution of twin-core fiber optical tweezers (TCFOT) is calculated using FDTD-BPM method. It is found that there is an optimum for core index to have maximum peak at far-field of a tapered TCFOT.**

Keywords- optical tweezers; twin-core fibers; far-field pattern; finite difference time domain

I. INTRODUCTION

After the works of Ashkin *et. al.* [1], [2], there are many reported applications for optical tweezers in optics, pico-newton forces and biology. In these structures, a propagating laser beam which is tightly focused inside the fibers is utilized. Using this concept, multiple particle trapping is developed [3]-[5]. Electrostatic interaction between a single fiber optical tweezers and the particle to be trapped has been reported [6]. But, in this method the trapping point is very close to the fiber tip so the particle trapping can not done practically [7], [8].

Interesting features are obtained for the optical forces of shaped particles; for example, cubes, rectangles, cylinders, and core-shell composite particles. Some parameters such as the orientation of particles with respect to the laser beam propagation and polarization direction and the aspect ratio of the anisotropic particle affect the optical force strongly. Indeed, to have stronger force the shape of tweezers used for particle trapping is important and it is due to the confined fields at the tip of the fibers.

II. THEORY AND STRUCTURE OF TCFOT

Fabrication of TCFOT has relatively complicated as explained in [5]. A Mach-Zehnder interferometer to generate two beams is shown in Fig. 1 [5]. As shown, this twin-core interferometer is linked with the tapered twin-core fiber and because of the bending in the interferometer the propagated fields in two cores are modulated. Many parameters can affect on the output field intensities and by using this, we may have a good control of the particle trapping. Tapering of fibers at the tip of this structure and its formation is based on the Yuan's works in [5]. At the fiber outputs, two beams are used for particle trapping and the amount of the applied force can be calculated by determining the far-field pattern of these beams at a fixed distance along the z-axis [2], [3].

At the output or tip of TCFOT, it is possible to calculate the near field of the structure using three dimensional finite difference time domain beam propagation method (3D-FDTD-BPM). Assume that the twin-core fiber is immersed in a medium with low index of refraction; which we selected it to be 1.33. The core and clad of the fibers have the indices of 1.463 and 1.452, respectively. Three dimensional finite difference analysis is applied for the structure as offered in [8]. The boundaries are considered as perfectly matched layers too. A typical cross-section of TCFOT and its various peripheral indices are plotted in Fig. 1.

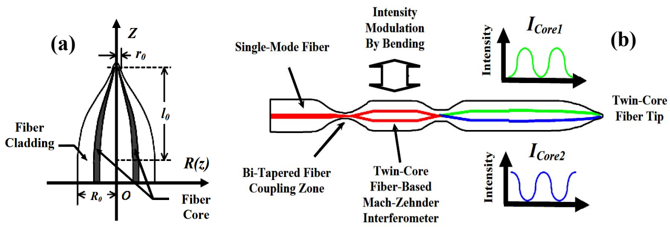

Figure 1. a) Typical structure of a TCFOT, b) its configuration [5].

The Gaussian incident optical power is assumed:

$$P_0(r) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{r^2}{2\sigma^2}} \quad (1)$$

where σ is the spot size and it was chosen about $1.85\mu m$ [5].

The fiber bending is an important parameter for this structure, since for sharp bending there is a high energy radiation and in the case of gradual bent the fiber length would be increased. We checked the different configurations for above TCFOT and found that, there are higher near-field intensities for the special curvature proposed by [5] using the following mathematical description for the fiber bending:

$$R(z) = \begin{cases} \frac{1}{2}(R_0 - r_0) - \frac{1}{2}(R_0 + r_0)\left\{\frac{\tanh\left[v\left(z - L/2\right)\right]}{\tanh\left(v L/2\right)}\right\}, & 0 < z < l_0 - r_0 \\ \sqrt{r_0^2 - (z - l_0)^2}, & l_0 - r_0 \le z \le l_0 \end{cases} \quad (2)$$

In this equation v is the tapered fiber profile parameter, L is total fiber length and other variables are shown in Fig. 1 which we considered them as [5]:

$R_0 = 625; r_0 = 2.5; l_0 = 201.5; L = 288$; all in μm, $v = 0.018(\mu m)^{-1}$.

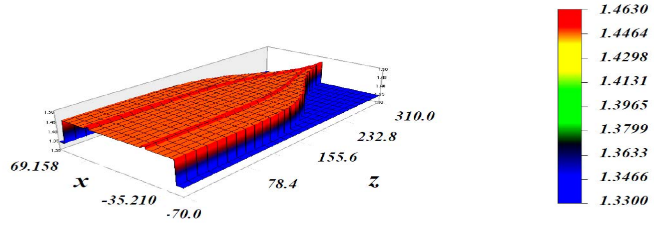

Figure 2. Indices of different media in TCFOT

III. Numerical Results

At first, we calculated the far-field pattern of TCFOT for core and clad indices of 1.46 and 1.452 respectively with $\lambda = 0.98 \mu m$. Our method was based on the FDTD-BPM, as proposed in [5]. The results are plotted in Fig. 3.

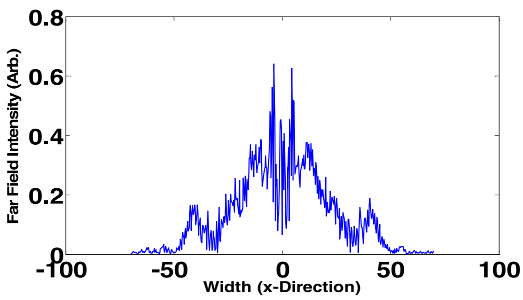

Figure 3. Far-field distribution of TCFOT with the core index of 1.46.

For these values there is a large amount of power extended in a wide range under two peaks of the far-field pattern which means smaller force for particle trapping. Repeating the procedure for core indices of 1.47 with the same clad, can causes the appearance of more flattened intensities at the far-field pattern. In other words, increasing the core index reduces the amount of power around the peaks of far-field pattern and increases the peak values, as shown in Fig. 4. This is equivalent to more power for particle trapping.

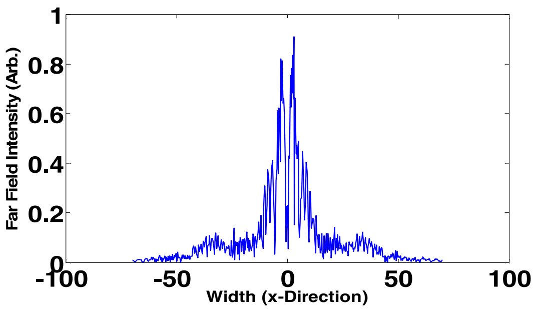

Figure 4. Far-field distribution of TCFOT with the core index of 1.47.

At the next step, we increase the core index up to about 1.482 and found the far-field pattern with same clad index. Increasing the core index to this value, has a dramatic effect on far-field pattern because the two peaks move closer and eventually merge to yield a single lobe far-field pattern which means lower powers. So, depends on the structure parameters, there is a proper amount for the core index to have maximum two-peak intensity or maximum trapping power. To achieve this optimum, we calculated the force generated by far-field using the Poynting vector numerically over a constant z-plane. The results are plotted in Fig. 5.

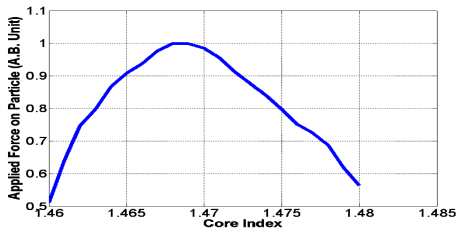

Figure 5. Illustration of particle applied force versus the core index.

For the core index of 1.4684 there is a maximum trapping force with respect to the reported value of 1.463 [5].

IV. Conclusions

In this paper, typical structure of TCFOT is analyzed and simulated using the FDTD-BPM. The trapping force of TCFOT is calculated and it is found that there is an optimum value for the core index to have maximum trapping force. Using an optimum cord index, it is possible to increase the trapping force by a factor of about 2.

References

[1] A. Ashkin, J. M. Dziedzic, J. E. Bjorkholm, and S. Chu, "Observation of a single-beam gradient force optical trap for dielectric particles," Opt. Lett. vol. 11, pp. 288-290, 1986.

[2] A. Ashkin, J. M. Dziedzic, and T. Yamane, "Optical trapping and manipulation of single cells using infrared laser beams," Nature vol. 330, pp. 769-771, 1987.

[3] N. B. Simpson, K. Dholakia, L. Allen, and M. J. Padgett, "The mechanical equivalence of the spin and orbital angular momentum of light: an optical spanner," Opt. Lett. vol. 22, pp. 52-54, 1997.

[4] I. Cristiani, C. Liberale, and P. Minzioni, "Method and optical device for trapping a particle," PCT Patent Application PCT/EP/2007/056798, Jul. 5, 2007.

[5] L. Yuan, Z. Liu, J. Yang, and C. Guan, "Twin-core fiber optical tweezers," Opt. Exp., vol. 16, pp. 4559–4566, 2008.

[6] R. S. Taylor and C. Hnatovsky, "Particle trapping in 3D using a single fiber probe with an annular light distribution," Opt. Exp., vol. 11, pp. 2775–2782, 2003.

[7] P. Minzioni, F. Bragheri, C. Liberale, E. D. Fabrizio, and I. Cristiani, "A Novel Approach to Fiber-Optic Tweezers: Numerical Analysis of the Trapping Efficiency," IEEE, J. STQE., vol. 14, pp. 151-157, 2008.

[8] K. N. Kuo, and K. Y. Chen, "Integrated single-beam optical tweezers and planar curved grating for multiple optical traps," 5th IEEE International Conference on Nano/Micro Engineered and Molecular Systems (NEMS), 20-23 Jan. 2010, 195-198.