

Regular Articles

An all fiber apparatus for microparticles selective manipulation based on a variable ratio coupler and a microfiber



Baoli Li, Wei Luo, Fei Xu*, Yanqing Lu

National Laboratory of Solid State Microstructures, and College of Engineering and Applied Sciences, Nanjing University, Nanjing 210093, People's Republic of China

ARTICLE INFO

Article history:

Received 17 December 2015

Revised 5 April 2016

Accepted 10 July 2016

Keywords:

Variable ratio coupler

Micro particle manipulation

Microfiber

ABSTRACT

We propose an all fiber apparatus based on a variable ratio coupler which can transport microparticles controllably and trap particles one by one along a microfiber. By connecting two output ports of a variable ratio coupler with two end pigtailed of a microfiber and launching a 980 nm laser into the variable ratio coupler, particles in suspension were trapped to the waist of microfiber due to a gradient force and then transported along the microfiber due to a total scattering force generated by two counter-propagating beams. The direction of transportation was controlled by altering the coupling ratio of the variable ratio coupler. When the intensities of two output ports were equivalent, trapped particles stayed at fixed positions. With time going, another particle around the micro fiber was trapped onto the microfiber. There were three particles trapped in total in our experiment. This technique combines with the function of conventional tweezers and optical conveyor.

© 2016 Elsevier Inc. All rights reserved.

1. Introduction

Optical tweezers was proposed by Ashkin in 1986 [1], since then it has been widely used for particles manipulation in the fields of physics and biology due to the noncontact manipulation of objects. In the early days, much work was done mainly based on a highly focused laser beam through a high numerical aperture microscope objective. In these systems, optical manipulation are quite complicated and costly. In order to simplify the trapping system, optical fiber tweezers based on etched fiber tips have been developed since 1993 [2]. Compared to conventional tweezers, optical fiber tweezers are more low cost and convenient to realize particles levitating [3], moving [4] and rotating [5]. However, a much short focal depth of optical fiber turns the continuous transportation of particles into a challenge. To overcome such limitation, microparticles manipulation using the evanescent field of planar waveguides appeared [6]. Compared to planar waveguides fabricated on substrates, optical fibers is more freestanding, and the small size makes it compatible to be integrated on a chip. As a result, works about trapping and continuous transportation of particles by the evanescent field of optical fibers have been reported [7,8]. Nevertheless, in these works, transportation of particles is usually unidirectional. There have been several reports on the bidirectional optical transportation of particles. Grujic et al.

reported a dielectric microsphere manipulation by counter-propagating waves in a channel waveguide [9]. Zhao et al. reported an optical trapping by counter-propagating beams in nanofiber theoretically [10]. Lei et al. reported a bidirectional optical transportation by using two incoherent beams [11].

In this paper, we not only achieve bidirectional particles transportation but also selective particles trapping based on a variable ratio coupler. Two output ports of the variable ratio coupler and two end pigtailed of a 1 μm diameter microfiber were connected into a loop. Due to the evanescent field of a microfiber, particles around the waist of microfiber in suspension were trapped and then transported along the microfiber. The direction of transportation can be controlled by altering the intensity ratio of two counter-propagating beams through adjusting the coupling efficiency of the variable ratio coupler. Once the intensities of two counter-propagating beams were equivalent, the trapped particles kept still at fixed positions. At the same time, particles not trapped may run into the potential well of the microfiber and then be trapped onto the microfiber. There were three particles trapped one by one in the following experiment. In such a way, we achieved a selective trapping of particles. Such manipulation can apply to particles ranging in size from hundreds of nanometers to several micrometers.

2. Theory of force calculation

The optical force acting on a particle is defined as:

* Corresponding author.

E-mail address: feixu@nju.edu.cn (F. Xu).

$$F = \oint_S \langle \langle T_M \rangle \cdot n_s \rangle dS \quad (1)$$

where n_s is the normal vector of the surface around the particle pointing outward, T_M is the Maxwell stress tensor which is given by:

$$\langle T_M \rangle = DE^* + HB^* - \frac{1}{2}(D \cdot E^* + H \cdot B^*)I \quad (2)$$

where E , D , H and B denote the electric field intensity, the electric displacement, the magnetic field intensity and the magnetic flux, respectively. I is the isotropic tensor, and E^* and B^* are the complex conjugates. Fig. 1a shows the variation of gradient force and scattering force versus diameters of particles when there is only one laser beam is launched. For the simulation, the gap between particle and microfiber is assumed to be 100 nm. A 980 nm laser is launched, the refractive index of the microfiber, water and silica particles are 1.445, 1.33 and 1.46, respectively.

A microfiber of 1 μm in diameter is illuminated by two counter-propagating beams, beam 1 and 2, which propagate along $+z$ and $-z$ direction, respectively. It is assumed that the length of the microfiber is L and the left end face of the microfiber is set to be $z = 0$. The electric fields of beam 1 and 2 at $z = z_0$ are presented as E_1 and E_2 , respectively.

$$E_1 = A_1 \exp j(\omega t + \varphi_0 + (2\pi/\lambda)z_0) \quad (3)$$

$$E_2 = A_2 \exp j(\omega t + \varphi_0 + \pi/2 - (2\pi/\lambda)(z_0 - L)) \quad (4)$$

where A_1 and A_2 are amplitudes of beam 1 and 2, respectively, ω is the angular frequency of beams, λ is the wavelength of the laser beam, φ_0 is the initial phase of beam 1 at $z = 0$. Therefore the total interference electric field is

$$E = A \exp(j\varphi t) \quad (5)$$

where

$$A = [A_1^2 + A_2^2 + 2A_1A_2 \cos(\pi/2 + (2\pi/\lambda)L - (4\pi/\lambda)z_0)]^{1/2} \quad (6)$$

$$\varphi = \frac{A_1 \sin(\omega t + \varphi_0 + (2\pi/\lambda)z_0) + A_2 \sin[\omega t + \varphi_0 + \pi/2 - (2\pi/\lambda)(z_0 - L)]}{A_1 \cos(\omega t + \varphi_0 + (2\pi/\lambda)z_0) + A_2 \cos[\omega t + \varphi_0 + \pi/2 - (2\pi/\lambda)(z_0 - L)]} \quad (7)$$

Generally, there are two kinds of optical force acting on a dielectric particle due to the interaction between the evanescent field of the microfiber and the object. The gradient force used to trap an object is caused by the intensity gradient in a nonuniform field. The other force, namely the scattering force, is generated due to the scattering and absorption of the incident field by the dielectric particle. Scattering force is the reason for transportation of particles along the microfiber. In the Rayleigh regime, scattering force is proportional to the energy flux and points along the direction of propagation of the incident light. In the Mie regime, scattering force depends on the deflection of incident light. There is an analytic solution for Mie spherical objects, which describes the scattering of a plane wave by a dielectric sphere. However, much complicated computation is needed to find the full solution. For simplicity, the direction of Mie particles can be explained by the energy flux qualitatively. Fig. 1b shows the variation of energy density flux versus positions in z axis when the intensity ratios of two counter-propagating beams are 10:1, 1:10 and 1:1. As the figure shows, the variation of energy density flux in such interference fields is sinusoidal. However, the large diameters of micro particles used in our experiment compared to the wavelength in the medium cancel such a variation trend. The total scattering force is an

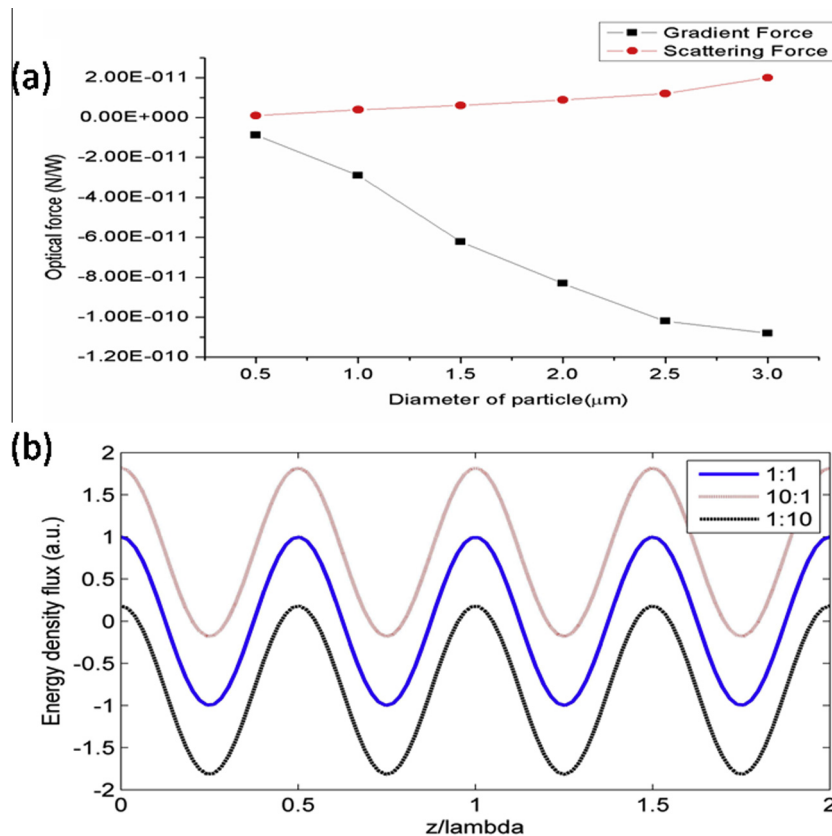


Fig. 1. (a) The variation of gradient force and scattering force acting on particles versus diameters of particles with one beam launched. (b) The variation of energy density flux along the microfiber corresponding to different power ratios of two counter-propagating beams.

Download English Version:

<https://daneshyari.com/en/article/464292>

Download Persian Version:

<https://daneshyari.com/article/464292>

[Daneshyari.com](https://daneshyari.com)