Conference Paper

Manipulation of Microparticles By Bessel Light Beam

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Abstract

We consider perspectives of optical manipulation of microscopic objects in the area of biology, biophysics and medicine. The first part of the work is devoted to a brief review of the microparticles' manipulation. The second part contains calculations of the focusing of laser radiation parameters and some results on the formation of Bessel light beams. The experimental setup based on the optical manipulation technique of micron-sized particles was developed.

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1. Introduction

A non-contact device based on optical trapping is used to study micro- and nanoparticles. Optical trapping is a technology that uses a tightly focused light field for manipulating microscopic objects, and has a delicate influence on them [1]. Recently such device was used in microsurgery, pharmaceutics, biophysics to study the structure and operation principles of macromolecules [2] and in colloid chemistry to study objects such as charged colloidal particles in solutions [3]. Optical tweezers are relevant, because they can be used to study the elasticity of the membrane, unwinding force of the microtubules and associated protein that plays an important role in further understanding the kinetics of protein and cell membranes [4]. They also contribute to the study of DNA and aging [5].

The aim of this work is to develop a technique for forming of Bessel beams and to design an experimental setup of optical manipulation of micron-sized particles.

2. Material and Theoretical Bases of Research

Optical manipulation is applicable to such objects as dielectric particles ranging in size from tens of nanometers to hundreds of micrometers, for example biological objects: cells, viruses, microbes, DNA molecules [6]. There are some models of optical traps working on a Gaussian or Bessel light beams. In such optical traps, the particle trapping mechanism is based on the phenomena of optical levitation. Particles move along the light beam under the influence of the light field. The light refracts inside the particle and changes their direction as seen from Figure 1. When light is refracted by particles in solutions, the radial forces of light pressure appear, starting from the law of conservation of momentum. The intensity on the beam axis is greater than at the periphery, therefore Fa> Fb. In this case, the sum of the two forces will be directed to the beam axis. The displacement of particles from the point where the intensity of light is maximum leads to the appearance of a force that returns it to the equilibrium state. This principle is valid for microparticles with diameters greater than the light wavelength [7].

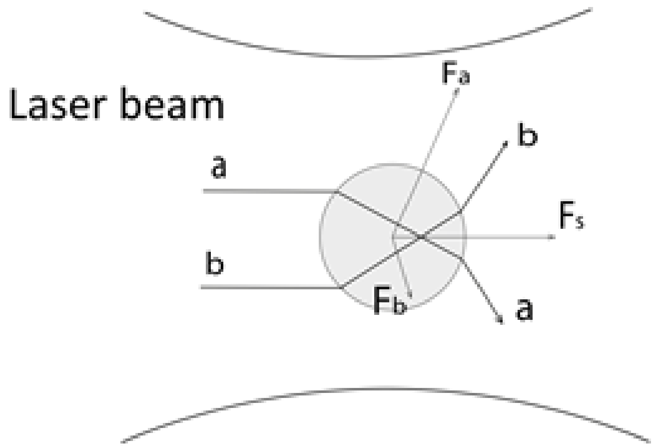

Figure 1: Scheme for the direction of radial forces.

Lasers provide light beams with the required intensity, so they are usually used in optical manipulation devices. The intensity distribution in such beams is described by the Gaussian function. The maximum energy is concentrated on the optical axis and rapidly decreases to the borders in accordance with the Gaussian function [8]. The importance of Gaussian beams is determined by the following properties. These beams have a Gaussian intensity profile in any point of the optical axis. The beam after passing through simple optical elements (for example lenses without aberrations) saves its Gaussian profile [9]. However, there are factors that limit the use of such beams in optical tweezers. One of the factors is related to the focusing of radiation. The more focused the beam, the faster it diverges after the focus. The force that holds the particle at a distance of several micrometers from the focus is insufficient to trap the particle [10].

Optical traps using Bessel beams are more effective. The Bessel beam is a light beam, the cross section of which consists of a central spot surrounded by concentric rings with gradually damped intensity [11]. Compare with Gaussian beams, the central maximum of Bessel beam offers a “non”-diffracting focal line of light. This is explained by the interference of a part of the waves passing through the object, converging behind it, and forming an undistorted beam. It is possible to manipulate several particles of different sizes at once [12].

There are several ways of forming of Bessel beams, in particular, by transforming the ring distribution of the light field. This method has a significant limitation: low efficiency due to the fact that most of the radiation is lost on the annular slot, which forms the relevant distribution of the light field [13]. However, there is a method in which all the radiation energy is used to form Bessel beams: passing the beam through the axicon [14]. The axicon has axial symmetry and, due to reflection and refraction, represents light from a point source into the axial section [15]. Another advantage is the image of a point with smaller aberrations.

3. Results

In this work we make use of Bessel light beams for optical manipulation of particles. Calculations of the optical system for forming a Bessel beam based on an axicon were made at this stage of the work. In this experiment we used an axicon with an angle at the vertex of 140° and a refractive index $n = 1.47$, a lens with a focal length $F = 5$ cm. The radius of the first ring is approximately 1 cm when passing a Gaussian beam with a radius of 1.1 cm and the focus of the axicon is 2.5 cm, the length of the focal spot is 1.6 cm. The obtain profile of the field distribution in a Bessel beam of zero order in the vertical direction is shown in Figure 2. Bessel beams with central maxima of 2-10 μm in diameter were presented here.

After the completion of the formation of the Bessel beam, we developed an experimental setup based on it, which shown in Figure 3. We illuminate axicon 10 mm in diameter with the expanded Gaussian output beam of a semiconductor laser 540 nm. The Bessel light beam was focused by an objective for increasing the size of the light beam to 5 mm. Microspheres with diameters in the range of 1-10 microns were used as a test objects. A microscope objective and CCD camera were placed above the sample for observation of trapped particles [16].

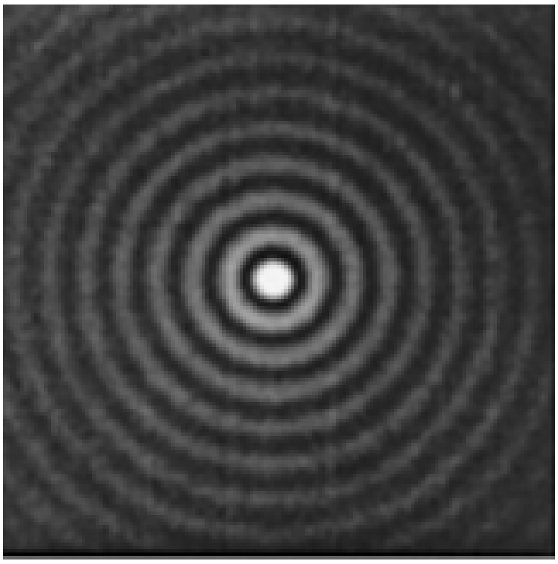

Figure 2: The obtain profile of the field distribution in a Bessel beam of zero order.

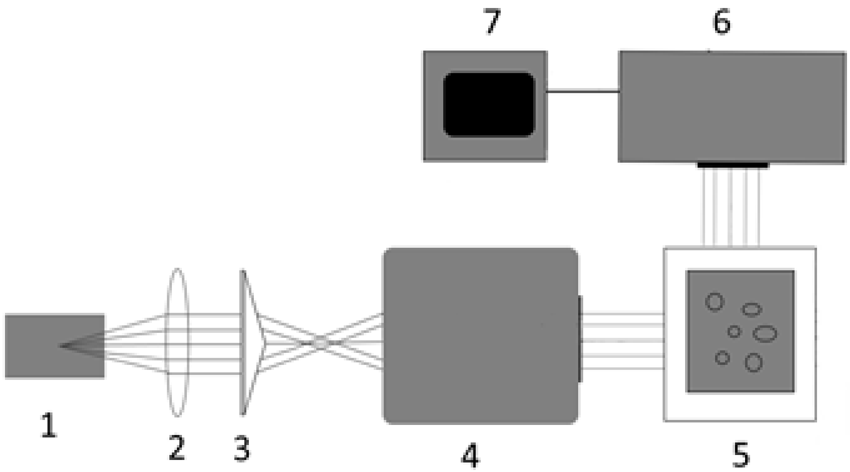

Figure 3: Schematic diagram of the experimental setup: 1 – laser, 2 – lens, 3 – axicon,, 4 – objective, 5 – cuvette with the studied liquid sample, 6 – microscope, 7 – video camera with CCD matrix.

4. Summary

The advantages and disadvantages of optical traps based on Gaussian and Bessel beams were considered. An optical scheme was developed for the formation of a zero-order Bessel beam. The results of preliminary measurements make it possible to conclude that this experimental setup is applicable for the trapping and manipulation of microparticles.

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