NON-DESTRUCTIVE OPTICAL TRAP FOR BIOLOGICAL PARTICLES AND METHOD OF DOING SAME

TECHNICAL FIELD

This invention relates to trapping of particles using a single-beam gradient force trap.

BACKGROUND OF THE INVENTION

Single-beam gradient force traps have been demonstrated for neutral atoms and dielectric particles. Generally, the single-beam gradient force trap consists only of a strongly focused laser beam having an approximately Gaussian transverse intensity profile. In these traps, radiation pressure scattering and gradient force components are combined to give a point of stable equilibrium located close to the focus of the laser beam. Scattering force is proportional to optical intensity and acts in the direction of the incident laser light. Gradient force is proportional to the optical intensity and points in the direction of the intensity gradient.

Particles in a single-beam gradient force trap are confined transverse to the laser beam axis by a radial component of the gradient force. Stabilizing the particle along the axis direction of the trap is achieved by strongly focusing the laser beam to have the axial component of gradient force dominate the scattering force in the trap region.

In prior work using single-beam gradient force optical traps on dielectric particles, trapping was demonstrated with a visible light laser source ($\lambda=514.5$ nm.) focused by a high numerical aperture lens objective. See A. Ashkin et al., *Optics Letters,* Vol. 11, p 288–90. The dielectric particles were closely spherical or spheroidal in shape and ranged in size from 10 μm diameter Mie glass spheres ($\alpha>>\lambda$) down to 260 Angstrom diameter Rayleigh particles ($\alpha\leqq\leqq\lambda$). Use of such regularly shaped particles in the Mie regime was desirable as taught in this and other articles.

For Mie particles, both the magnitude and direction of the forces depend on the particle shape. This restricts trapping to fairly simple shapes such as spheres, ellipsoids, or particles whose optical scattering varies slowly with orientation in the trap. In the Rayleigh regime, the particle acts as a dipole and the direction of force is independent of particle shape; only the magnitude of force varies with particle orientation.

It is not an insignificant result of the prior work that silica and other dielectric particles experienced varying amounts of irreversible optical damage from the trap. While it was suggested that the single-beam trap and the prior results would be extensible to biological particles, the resulting damage from exposure in the trap would destroy or significantly incapacitate the biological particles and render them useless. Also, since prior optical traps have been defined for quite regular-shaped, dielectric particles, their extension to biological particles is cast in doubt because regularity of shape is not an attribute of biological particles.

SUMMARY OF THE INVENTION

Biological particles are successfully trapped in a single-beam gradient force optical trap incorporating an infrared light source. Reproduction of trapped particles has been observed. After release from the trap, particles exhibit normal motility and continued reproductivity even after trapping for several life cycles at a high laser power of 160 mW.

In one embodiment, the higher numerical aperture lens objective in the single-beam gradient force trap is used for simultaneous viewing of the trapped biological particles.

Two single-beam gradient force optical traps are introduced into the same cell to permit three- dimensional manipulation of the biological particles.

BRIEF DESCRIPTION OF THE DRAWING

A more complete understanding of the invention may be obtained by reading the following description of a specific illustrative embodiment of the invention in conjunction with the appended drawing in which:

FIG. **1** is a cross-sectional schematic diagram of an embodiment of the invention;

FIG. **2** is a cross-sectional schematic diagram of an embodiment of the invention employing two single-beam gradient force traps in one cell; and

FIGS. **3** through **5** are schematic drawings of different modes of operation for an optical trap on particles in a cell.

DETAILED DESCRIPTION

Single-beam gradient force optical traps are useful for confining, isolating, translating and manipulating at least one particle in a group of particles enclosed in a cell or hanging droplet or the like. Special problems surface when the particles are biological. For example, absorption of the optical energy in the trap by the confined particle may lead to particle annihilation or a significant loss of particle motility. Also, as the wavelength of the light beam is varied to avoid the aforementioned problem, the intensity of the optical trap may be sufficiently decreased so as to be rendered ineffective for the particles of interest. While the wavelength selected may be sufficient for effective operation of the optical trap, it may be at a wavelength which is absorbed by the medium surrounding the particles and, therefore, which leads to heat generation within the cell. Clearly, many factors must be considered when selecting the operating wavelength for the optical trap.

In the prior optical trap experiments reports in the literature, particle sensitivity has not been an issue. This is generally attributed to the fact that dielectric particles have homogeneous compositions and uniformly regular shapes so that it is straightforward to observe the effect of the trap on one particle or portion of a particle and accurately predict the effect on other particles or on other portions of the same dielectric particle. For biological particles, sensitivity of the particles is extremely important. Biological particles have heterogeneous compositions and irregular shapes. Hence, the effect of the trap on one part of a biological particle is in no way determinative of the effect in another portion of the same particle.

FIG. **1** shows a cross-sectional schematic diagram of apparatus for creating a single-beam gradient force optical trap in accordance with the principles of this invention. IR laser **10** is a standard laser emitting a coherent light beam substantially in the infrared range of wavelengths, for example, 0.8 μm to 1.8 μm.

Light beam **11** from IR laser **10** impinges upon a combination of optics elements for focusing the light beam with a sufficient degree of convergence to form a single-beam gradient force optical trap for confining biological particles at a desired position. The combina-