Optical Trapping using Doughnut Beam

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1 Report

The principles of optical trapping were developed by Arthur Ashkin when he was trying to answer the question “Can we observe significant motion of small neutral particles using the forces of radiation pressure from laser light?”. In a series of papers, he demonstrated that optical forces could displace and levitate micron-sized dielectric particles in both water and air, and he developed a stable, three-dimensional trap based on counterpropagating laser beams. This seminal work eventually led to the development of the single-beam gradient force optical trap, or “optical tweezers”.
There are two forces which arise when we use a laser beam to trap a dielectric particle. Optical gradient force competes with the scattering force. Gradient force is the one keeping the particle stable in the trap while the scattering force tries to push the particle along the direction of propagation of beam. For a stable trap, we use an objective with high numerical aperture and magnification.
Different theoretical models have been developed to analyze these forces depending on size of the object in comparison with the wavelength of light used for trapping.
When the size of the particle is much larger than that of the wavelength of the light, we can use the ray optics approximation. When the size of the particle is much smaller compared to the wavelength of light, the Rayleigh regime or dipole approximation is used. For spherical particles of any size and refractive index, Mie theory can be used to obtain accurate results.The theory becomes much more complicated when the sample is non-spherical.
The optical forces exerted on the particle when it is displaced from its mean position in the trap are similar to that of a spring mass system, i.e. force is proportional to displacement. The trapping laser results in a harmonic potential energy basin within which the object can reside. The restoring force is a linear function of displacement x.
Optical tweezers have been used to probe the properties of DNA, cell membranes and composite structures such as chromatin and chromosomes. They also have been used to characterize the forces exerted by molecular motors such as myocin, kinesin and ribosomes. The discovery of anomalous attractions between like-charged colloidal particles was also possible due to optical trapping.
In a typical Gaussian beam, the central portion contributes the most to the scattering force, thus removing that portion decreases the scattering force which is a destabilizing force.
Using a hollow (or) doughnut shaped beam helps significantly. I will be pursuing the study on optical trapping using dark hollow beams.

2 References

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