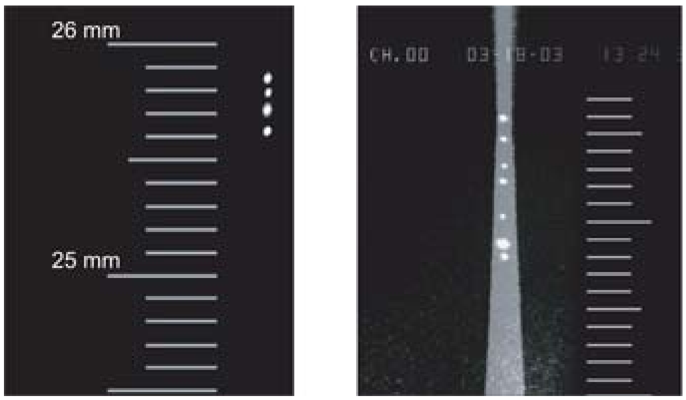
Optical Tweezers and Optical Trapping Improved for Future Automated Micromanipulation and Characterization

Optical trap arrays are being developed at the NASA Glenn Research Center for holding, manipulating, and optically interrogating arrays of nanotube sensors. The trap arrays, for example, might be used to arrange arrays of chemical sensors for insertion onto a chip in liquid, air, and vacuum environments. Neural-network-controlled spatial light modulators (SLMs) are to generate and control the trap positions and trap profiles in three dimensions.

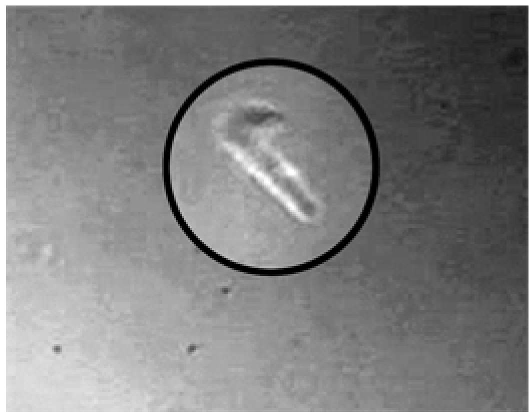


Left: Four 100-µm-diameter glass particles optically levitated to a height of over 25 mm. Right: Composite photograph illustrating the particle positions of optically levitated glass microspheres in the focused beam. The small scale divisions shown are in millimeters.

Long description of figure 1. Left: Four 100-micrometer-diameter glass spheres were optically levitated by a tightly focused laser beam incident on the spheres from below. The ruler scale to the left shows the approximate height from a glass plate to which the spheres were levitated. This height is greater than 25 millimeters, or just greater than 1 inch. Right: Several glass microspheres, typically 100 micrometers in diameter, were levitated above a glass plate by introducing a tightly focused laser beam from below. The unnumbered ruler scale on the right has its smallest divisions marked in millimeters so that one can estimate the relative distances between the spheres. The faint gray hour-glass shape shows the position of the focused area of the laser beam. This illustration shows the height of the beam waist with respect to the levitated spheres. The beam illustration is wider than the actual laser beam.

Glenn researchers have optically levitated glass and polystyrene microspheres in air. The preceding figure shows examples of microparticles optically trapped in air at Glenn. Typical object-to-lens distances for conventional microscope optical tweezers systems, where particles are confined to a liquid environment, are less than 5 mm. Previous maximum trapping distances from the focusing lens were 5 cm for levitated particles in air. Recently, Glenn researchers used a 135-mm-focal-length lens to levitate groups of test particles more than 25 mm above a glass plate, and more than 13 cm from the focusing lens. Groups of levitated particles can be raised and lowered by changing the height of the beam focus. In addition, levitated particles can be translated horizontally by changing the horizontal position of the beam focus.

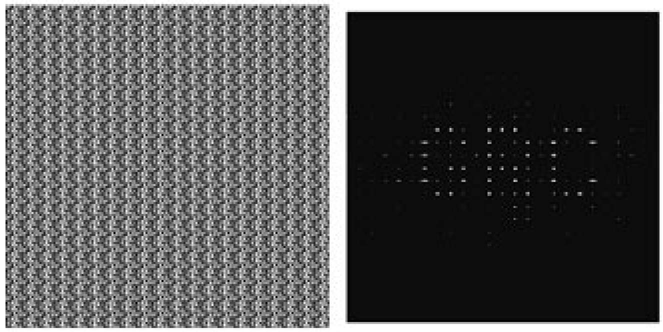
SLM-generated traps are used to position and rotate nanotube clusters in liquid. The SLM can be used to alter a trap profile to exert torque on a nanotube as well as to change its position. The following figure shows Laguerre-Gaussian (doughnut-mode) trap profiles exerting torques on nanotube clusters that are optically trapped in liquid.



Cluster of rotating silicon-carbide nanotubes trapped in a Laguerre-Gaussian optical trap. The rotation in this instance was counterclockwise.

Long description of figure 2. A cluster of silicon carbide nanotubes is optically trapped in a Laguerre-Gaussian mode trap of a tightly focused laser beam. This beam has a doughnut-like shape, dark at the center with a bright ring surrounding the dark spot. The nanotube cluster is bent near one end. The nanotube cluster is trapped by the light on the bright ring, and rotates counterclockwise in this case, with an angular momentum imparted by the helical nature of the phase front of the Laguerre-Gaussian mode beam.

Glenn also has developed techniques for matching the limited processing capability of neural-netware software to the full 480- by 480-pixel resolution of the SLMs. One technique is called tiling. In tiling, the 480- by 480-pixel scattered-light image from the trap array is scaled down to fewer than 10,000 pixels. Neural-network software can then easily be trained to generate a hologram of fewer than 10,000 pixels from the scaled image. The hologram might be intended to move a trap to a new position, for example. The reduced-size hologram is replicated, and the replicas are stacked or tiled to cover the full 480 by 480 pixels of the spatial light modulator. The left side of the following figure shows an array of 48- by 48-pixel holograms that were stacked to cover the full 480 by 480 pixels of the SLM and to generate the 480- by 480-pixel trap array shown on the right. Other stages of neural-network processing can be used to increase resolution and to perform sophisticated detection of scattered light profiles. A neural network can be trained to generate a hologram to move a trap to a particular location within an image tile. The hologram is scaled and added to a tiled hologram to move traps to anywhere in a 480 by 480 array of locations. A third class of networks can be used to detect slight changes in the axial-location-dependent light-scattering profiles from a sensor. This network can be used to control the third dimension of the sensor location.



Neural networks can easily generate smaller holograms. These can be tiled to control an SLM to generate the 480- by 480-pixel array of traps. Left: Array of 48- by 48-pixel holograms. Right: Corresponding array of optical traps.

Long description of figure 3. The pattern on the left, which resembles a moiré pattern, is a pattern that is sent by computer to a spatial light modulator (SLM). The SLM is an array of liquid crystals that is can be programmed to display a precalculated pattern. When the laser beam for the optical tweezers system is reflected off the pattern shown on the left and conditioned by the optical tweezers lens system, the optical traps that result appear as the picture on the right: an array of bright dots depicting the letters G, R, and C.

Bibliography

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