Optical Pipeline: Trapping and Guiding of Airborne Particles

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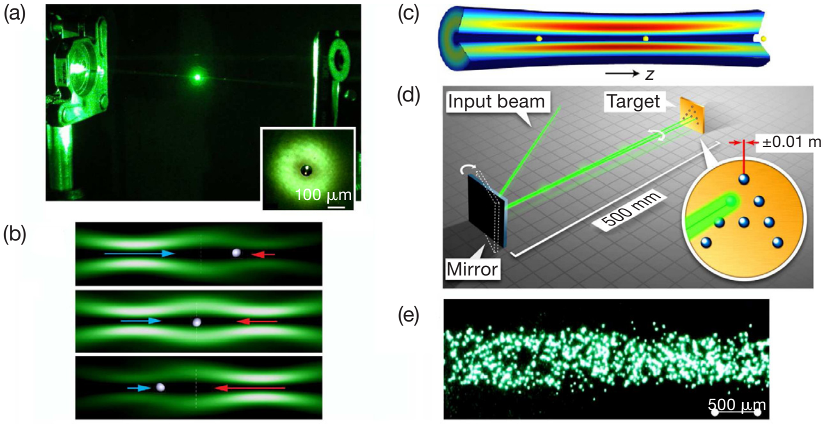


(a) Light scattered from trapped particle is visible in the center. (Inset) Glass microsphere suspended in the vortex beam. (b) Photophoretic trapping with two counter-propagating vortex beams; the imbalance of powers causes the particle to move to the right (left) if the left (right) beam becomes stronger; for equal powers, the particle sits in the center between focal planes. (c) Light intensity distribution in the vortex pipeline. (d) Delivery system based on the vortex pipeline. The position of the vortex beam can be varied by tilting the mirror. (e) Image shows multiple trapping of some 1,000 carbon particles in a speckle beam.

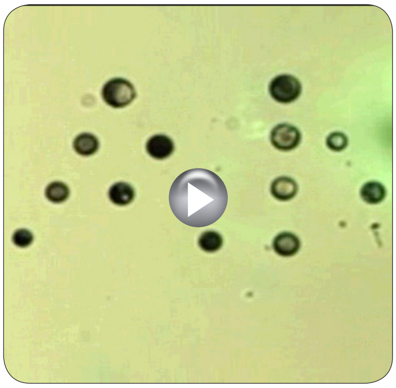
Optical manipulation of particles with lasers is an indispensable tool in many branches of science, from physics to biology and medicine.[1] Optical tweezers, which apply radiation pressure on transparent particles in liquids, are leading tools in this field. However, the efficient trapping of light-absorbing aerosol particles, such as air contaminants and novel nanostructured materials, represents a challenge because of dominating thermal or radiometric forces.[2]

When an incident light heats a surface of absorbing particle nonuniformly, gas molecules rebound off the surface with different velocities, thus creating an integrated photophoretic force. For positive photophoresis-absorbing particles are repelled from an intensity maximum, and stable trapping with Gaussian laser beams becomes impossible. Recently, we used two optical vortex beams[3,4] and created a new type of a stable trap for controlling absorbing particles in open air. The trap is formed between the focal planes of counter-propagating vortex beams. Optical vortices create a ring-shaped transverse intensity distribution, and the particles are trapped at the intensity minima. Consequently, the heating of trapped particles is minimal, which is important for *in situ* studies of particle properties.

To illustrate photophoretic manipulation of aerosols, we used clusters of carbon nanoparticles produced by a high-repetition-rate laser ablation with typical sizes between 0.1 and 10 µm as well as hollow glass spheres coated with a carbon layer to increase light absorption, with a typical size from 10 to 150 µm.

By retaining only a single vortex beam, the trap can be converted into an optical pipeline[5] for transporting particles over large distances in gases. We demonstrated the transport over 1.5 m, which is 1,000 times larger than any spatial scale of typical trapping schemes. Moreover, by tilting the vortex beam, the trapped particles could be delivered to the desired remote spatial location with accuracy better than 10 µm over a half-meter distance—which is like shooting a dime from 500 m. Further, using spatially modulated beams, we could trap many particles simultaneously.

Our approach can be applied for touch-free transport of containers holding gases, ultra-pure or dangerous substances, viruses or living cells. The dual-beam optical pipeline, in particular, allows such movement in opposite directions, acceleration up several centimeters per second, or holding containers anywhere in the pipeline. The method is well suited to many light-absorbing materials and ambient gases or liquids, and thus can be applied in studies of various airborne particles. ◭



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