Particle image velocimetry for visualizing laser-induced motion of nanoparticles

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Nanometer-sized gold particles interacting with electromagnetic fields, fluids, and biological objects can be visualized using a specialized imaging technique combined with dark field microscopy.

The pressure of electromagnetic waves, experimentally discovered in the early twentieth century, produces forces that affect objects scattering or absorbing light. With ordinary light sources these forces are feeble indeed and were considered unimportant before the invention of lasers in the 1960s. In the early 1970s, Arthur Ashkin demonstrated that a focused laser beam provides light pressure sufficient to displace and even levitate microscopic objects. This work eventually led to the development of ‘optical tweezers’ employed for motion control of microscopic objects in physics, chemistry, and biology.

Applying the concept of light pressure force to nanoparticle and laser technologies represents a further instrumental advance. In the past decade, noble metal nanoparticles have found broad application in biotechnology and nanomaterials. But the displacement of nanoparticles by light pressure requires much less intensity than is required to trap it in ‘optical tweezers’. Laser-driven nanoparticles have a variety of potential uses in nanofluidics, nanobiotechnology, and biomedicine.

Although the possibility of optically trapping gold nanoparticles was demonstrated in 1994, developing tweezers for nanoparticles is not straightforward. The gradient forces that are responsible for trapping, fall off with particle size. Moreover, the non-negligible absorption by particles leads to a dramatic temperature rise at high power, destabilizing single beam optical traps.

Recently we visualized nanoparticles moving along a laser beam under light pressure by micron-resolution particle image velocimetry (PIV). PIV records images of two successive moving particles, separated by a known time delay. Each image is divided into uniformly distinct interrogation regions, cross-correlated to determine, with greatest probability, local displacement of particles and flow velocity for each region.

To observe the translation of nanoparticles along the laser beam, we designed experiments based upon the conventional

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Figure 2. Dark field image of 40nm gold nanospheres on the glass substrate. Inset: magnified diffraction-limited image of a single nanosphere. Scales correspond to the object plane.

Figure 3. Velocity distribution of 40nm-diameter gold nanospheres moving in a 75mW laser beam under light pressure forces.

upright microscope (see Figure 1). The optical system consisted of an 8× objective and additional lens to deliver the radiation of a 75mW red (λ=660nm) laser diode to the object plane of the microscope perpendicular to the viewing direction. To make the nanoparticles visible, we used a dark field condenser (see Figure 1, inset). Only light scattered by nanoparticles reached the objective and formed the particle image as diffraction-limited spots (see Figure 2). In our setup with a 40× (numerical aperture 0.65) objective, a 40nm nanosphere, due to diffraction, appears through the microscope as a 1.5μm diameter circle on the object plane (see Figure 2, inset). The local velocity distribution of particles moving under light pressure in the laser beam focused along a 20μm diameter waist is shown in Figure 3. The flow induced by moving particles makes water circulate at the beam periphery and, as conveyed by the image, the nanoparticles tend to move away from the beam.

The use of PIV in combination with laser beams offers a novel approach for the study of nanoparticle interaction with electromagnetic fields, fluids, and biological objects such as cells and microorganisms. One current application of the proposed technique is the study of nanoparticle delivery and nanocluster formation for optical imaging in cancer diagnostics and therapy.

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