



Phys 6715 - Biomedical Physics:

Optical Trapping in Air

Yong-qing Li, PhD

Department of Physics, East Carolina University
Greenville, NC 27858, USA

Email: liy@ecu.edu

Outline

1. Why optical trapping airborne particles in air?

2. Forces for optical trapping

- Radiation pressure
- Gradient force
- Photophoretic force

3. Different schemes of optical trapping in air

- Optical levitation and trapping by radiation pressure
- Single-beam gradient-force optical trap
- Vortex beam trapping and transportation
- Single Gaussian beam and bottle beam trapping

4. Analysis of optically trapped airborne particles

I. Why trapping particles in air?

- ❑ **Particulate matter (PM)** suspended in air is a major contribution to the degradation of indoor and outdoor air quality. Particle pollution (also known as PM) in the air includes a mixture of solids and liquid droplets.
- ❑ **Fine particles (PM_{2.5})**. Particles less than 2.5 micrometers in diameter are called "fine" particles. Sources of fine particles include all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes.
- ❑ **Coarse dust particles (PM₁₀)**. Particles between 2.5 and 10 micrometers in diameter are referred to as "coarse." Sources of coarse particles include crushing or grinding operations, and dust stirred up by vehicles traveling on roads.

- ❑ Airborne particles is of importance in analyses related to monitoring air pollution, human health, and global climate change . Those less than 10 micrometers in diameter (PM10) are so small that they can get into the lungs, potentially causing serious health problems.
- ❑ Aerosol particles may include:
 - ❑ Water droplets or snow (0.01-1.0 mm in dia.) in outdoor air.
 - ❑ Soil, soot, mineral dust, sea salt, and textile particles (1 mm to >1 mm). Some are toxic for human.
 - ❑ Biological particles: bacteria, spores, pollen, fungi, viruses, etc. Some cause human diseases.
- ❑ Development of new means of sampling and chemical analysis of atmospheric microorganisms and individual aerosol particles is a fundamental aspect of environmental and atmospheric science.

Characterization of atmospheric biological particles using confocal Raman spectroscopy and optical trapping

- Goal: to develop and apply innovative confocal Raman micro-spectroscopy and optical trapping methods to measure and characterize single atmospheric particles.

- Specific aims include:
 - (1) Development of a novel LTRS bioaerosol-analyzer instrument for the collection of Raman spectra of single airborne biological particles that are impacted into background-free liquids or on solid microscope slides;
 - (2) Characterization and discrimination of airborne microorganisms based on Raman spectra;
 - (3) Optical trapping and identification of single aerosol particles in air environments.

Optical Levitation by Radiation Pressure

A. Ashkin and J.M. Dziedzic

Bell Telephone Laboratories, Holmdel, New Jersey 07733

(Received 14 June 1971; in final form 13 August 1971)

The stable levitation of small transparent glass spheres by the forces of radiation pressure has been demonstrated experimentally in air and vacuum down to pressures ~ 1 Torr. A single vertically directed focused TEM₀₀-mode cw laser beam of ~ 250 mW is sufficient to support stably a ~ 20 - μ glass sphere. The restoring forces acting on a particle trapped in an optical potential well were probed optically by a second laser beam. At low pressures, effects arising from residual radiometric forces were seen. Possible applications are mentioned.

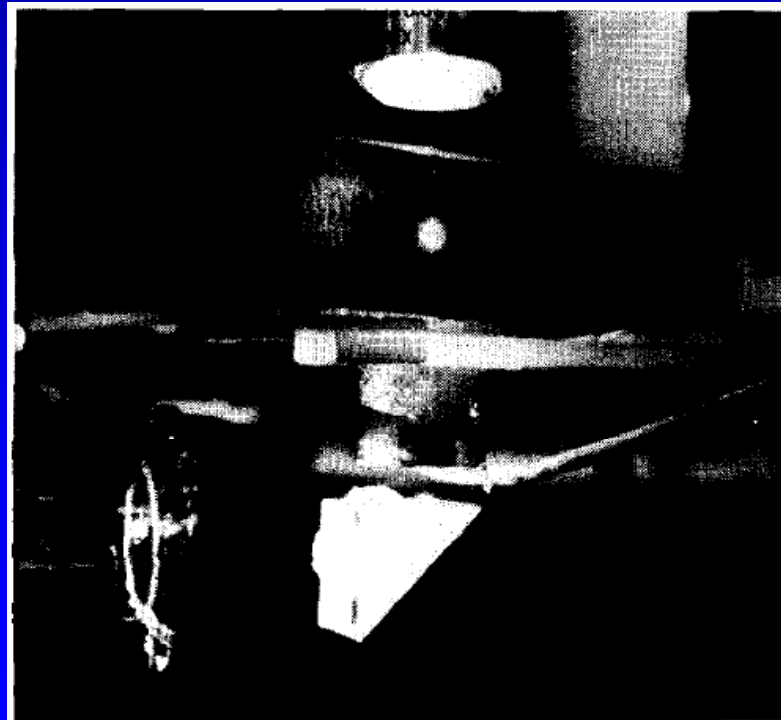
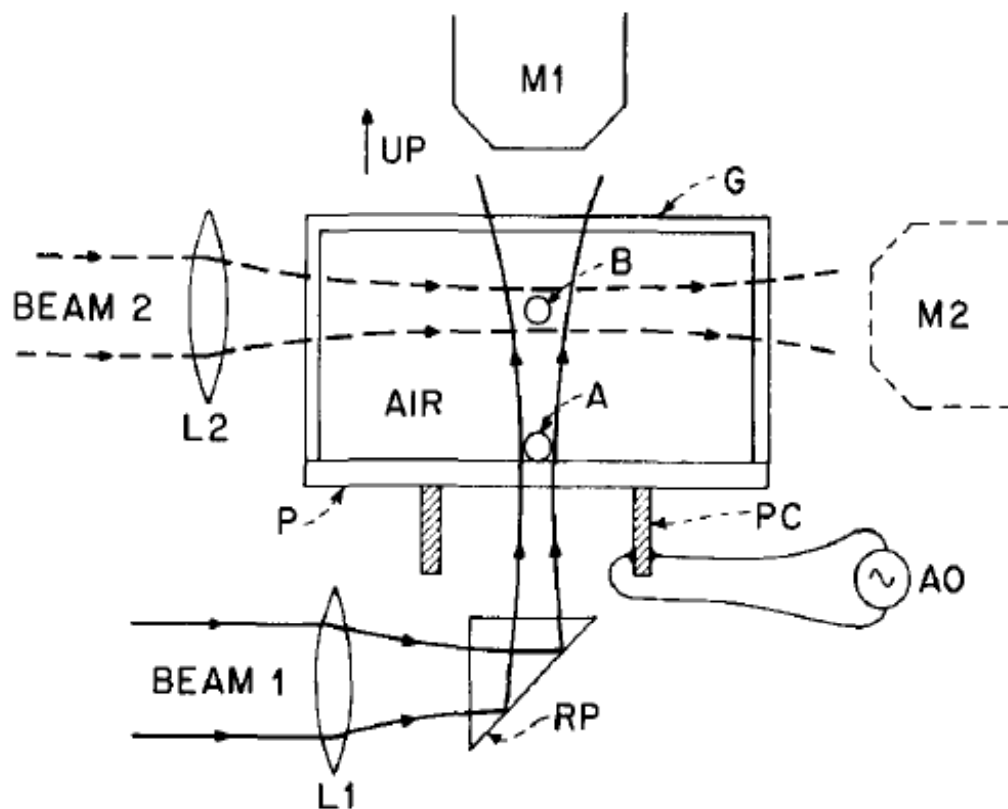
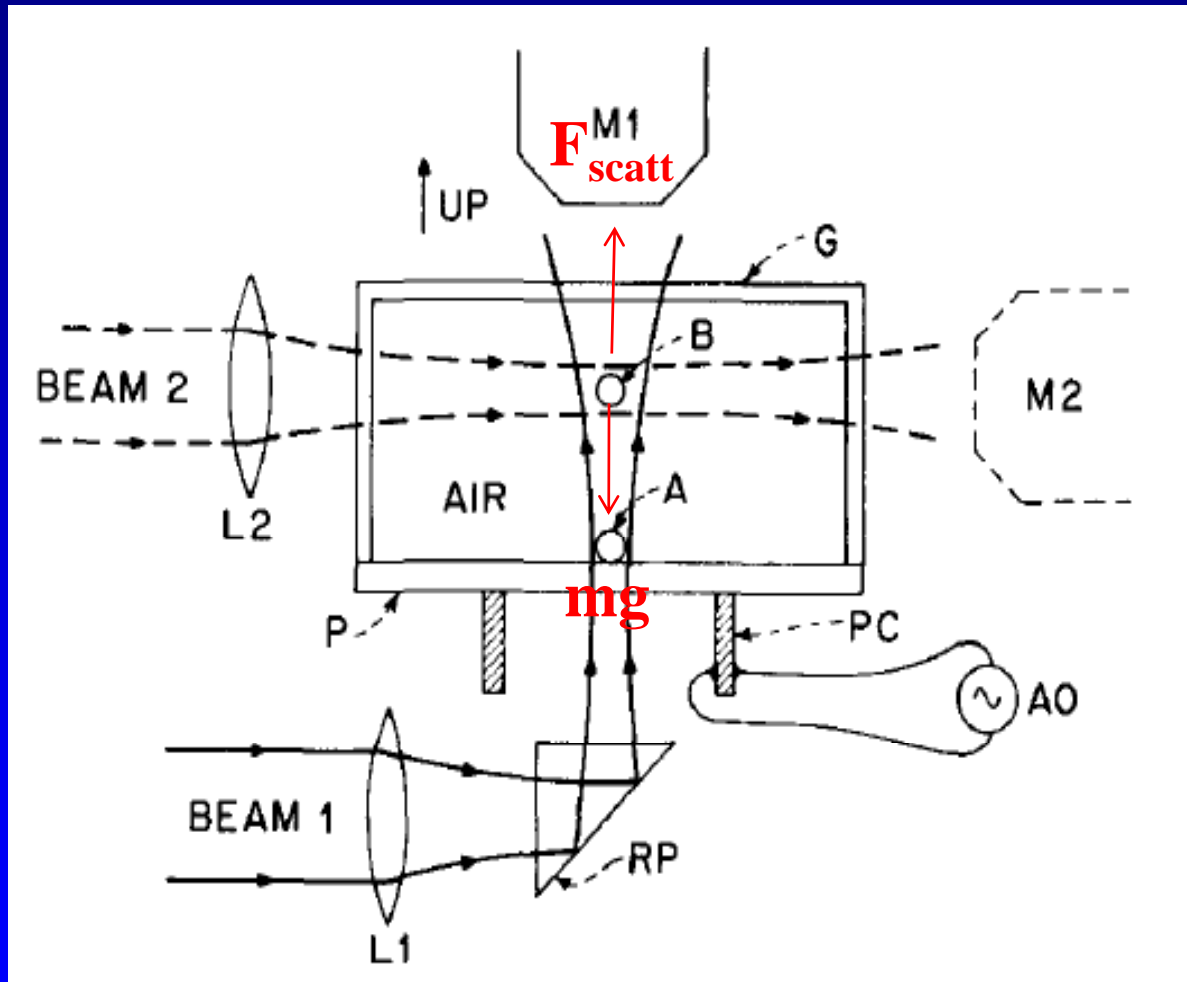


FIG. 2. Photograph of a ~ 20 - μ transparent glass particle being levitated about 1 cm above a glass plate by a 250-mW vertically directed laser beam (shown as beam 1 in

Radiation pressure



$$F_{\text{scatt}} = mg$$

$$F_{\text{scatt}} = nhk,$$

n – number
of scattered
photons per
second

Feedback stabilization of optically levitated particles

A. Ashkin and J. M. Dziedzic

Bell Telephone Laboratories, Holmdel, New Jersey 07733

(Received 5 November 1976)

We demonstrate the locking of an optically levitated sphere to an external reference using an electronic feedback system. This provides a new external source of damping for the stabilization and manipulation of particles in vacuum and at atmospheric pressure. The method permits accurate and continuous monitoring of applied forces. Numerous applications are suggested.

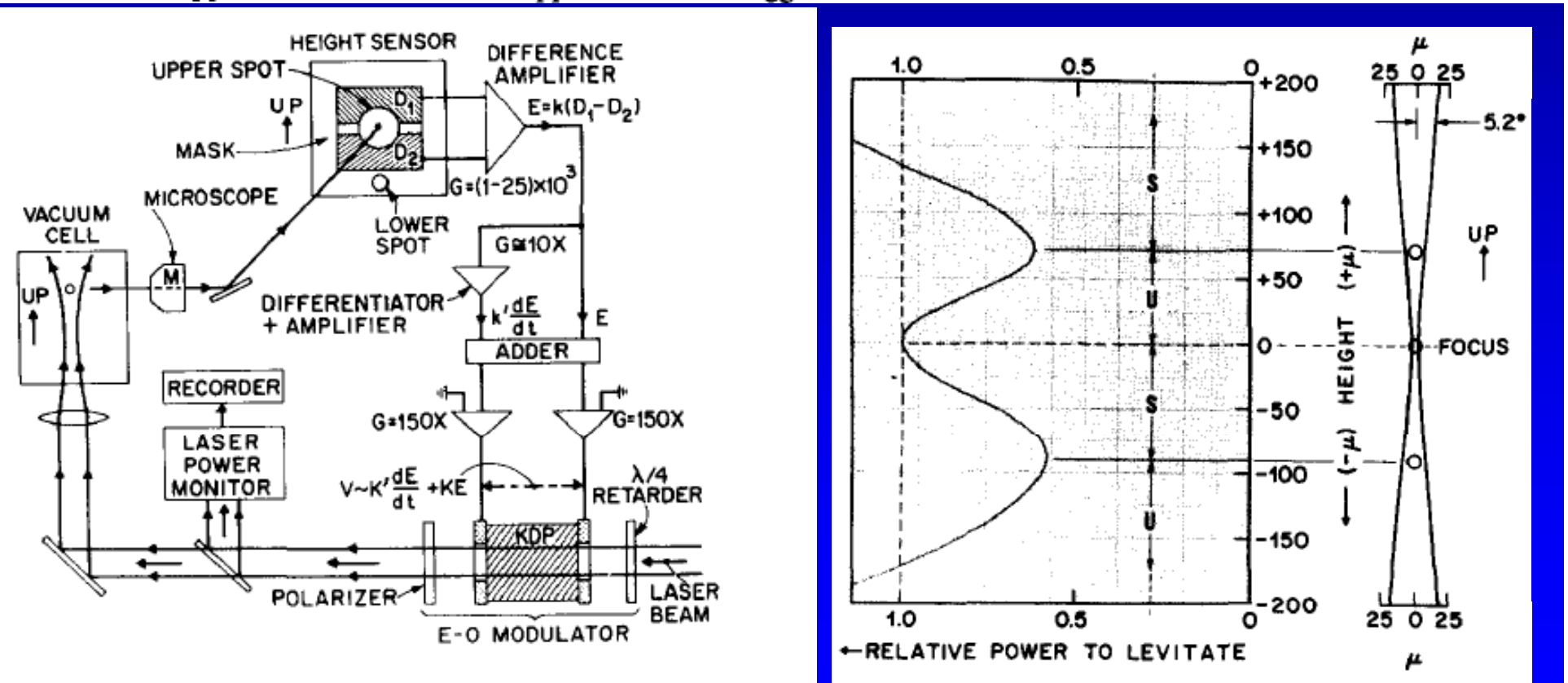


FIG. 1. Sketch of the feedback stabilization apparatus.

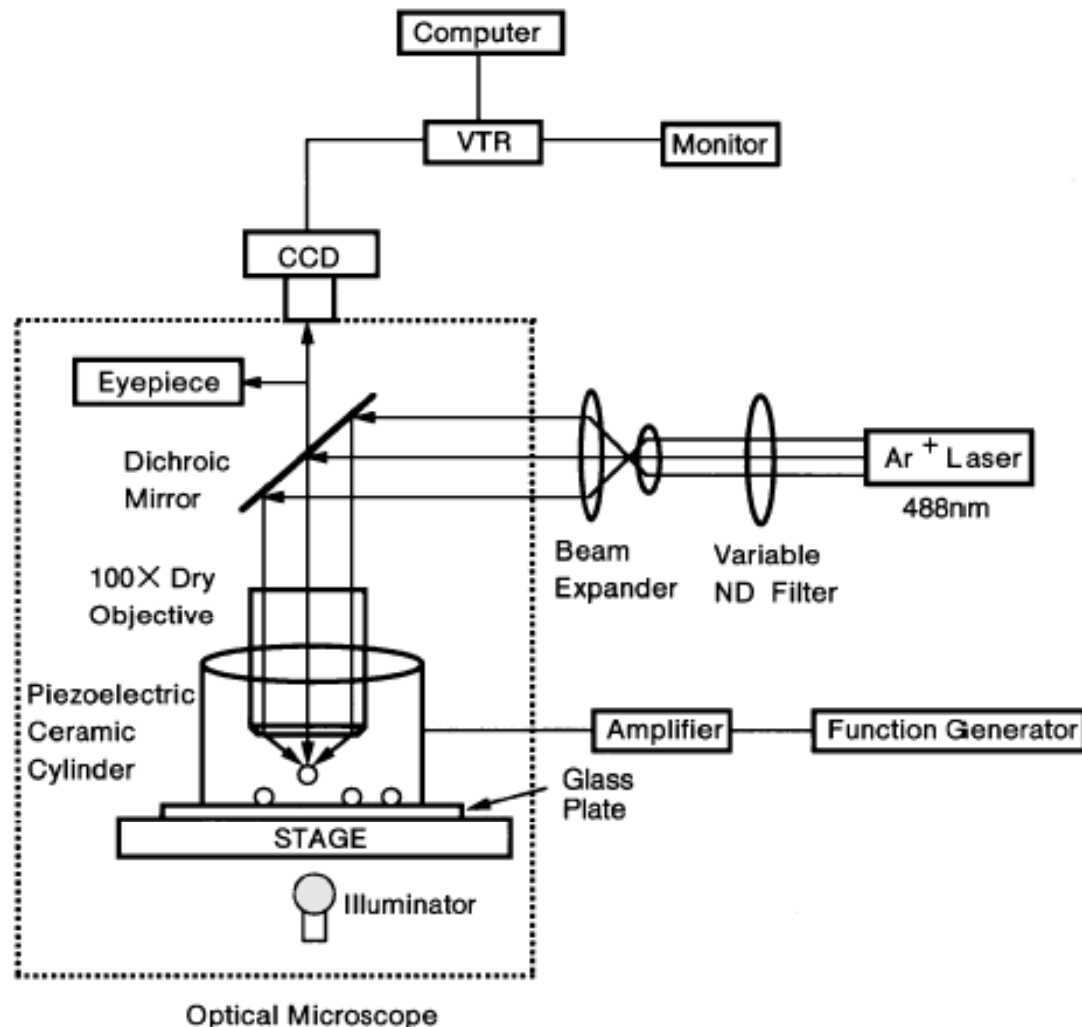
Observation of a single-beam gradient-force optical trap for dielectric particles in air

Shigeo Kuroda, Takashi Kamei, and Atsuyuki Suzuki

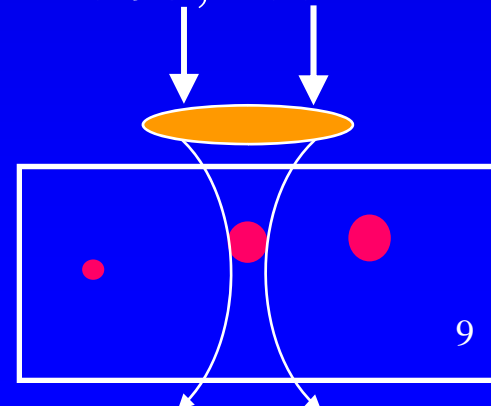
Department of Applied Physics, Faculty of Science, University of Tokyo, Tokyo 113, Japan

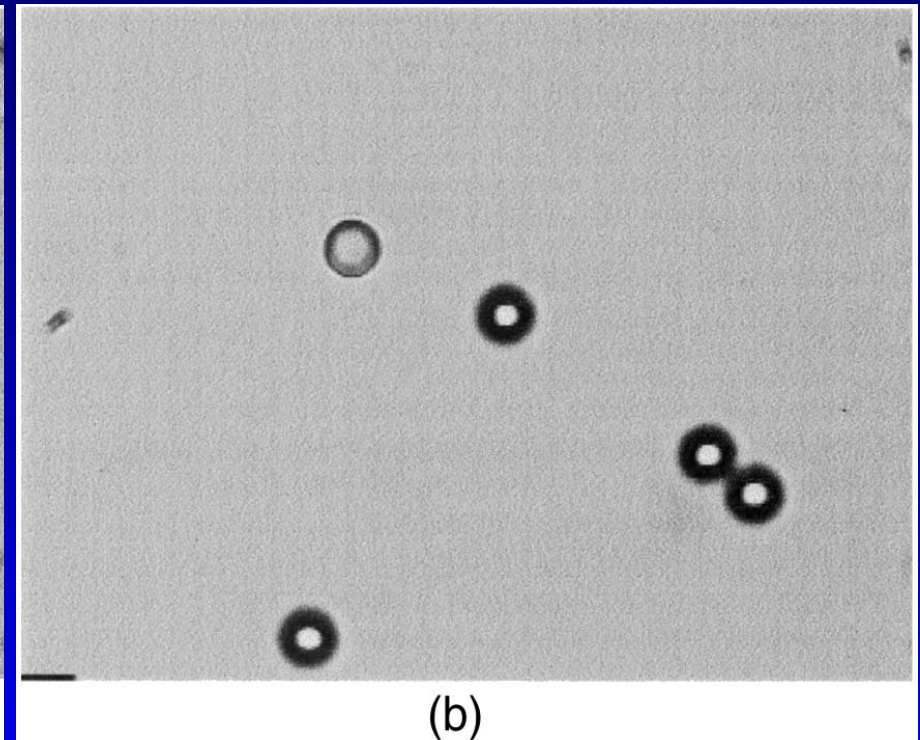
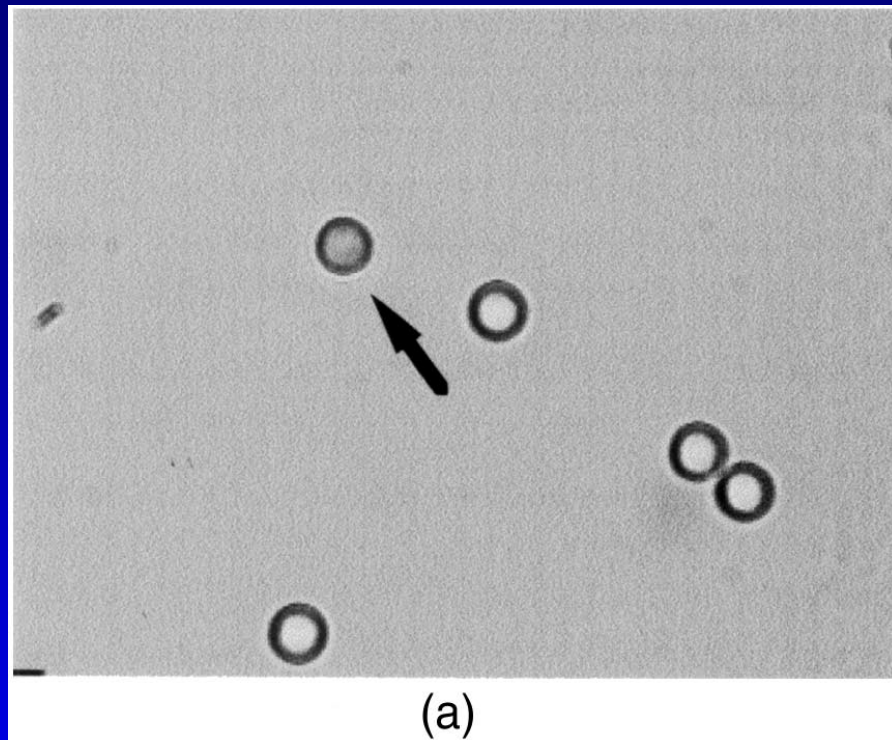
Received October 16, 1996

A single-beam optical trap for dielectric particles, which relies solely on the radiation pressure for what is believed to be the first time. It was demonstrated that a dielectric particle of refractive index of $n = 1.45$ remained trapped in the beam focus in a vacuum chamber three dimensionally by moving the beam focus sufficiently to trap a $5\text{-}\mu\text{m}$ -diameter glass sphere. This is the first demonstration of a single-beam optical levitation method. © 1997



Gradient force trapping,
NA=0.95, 100X



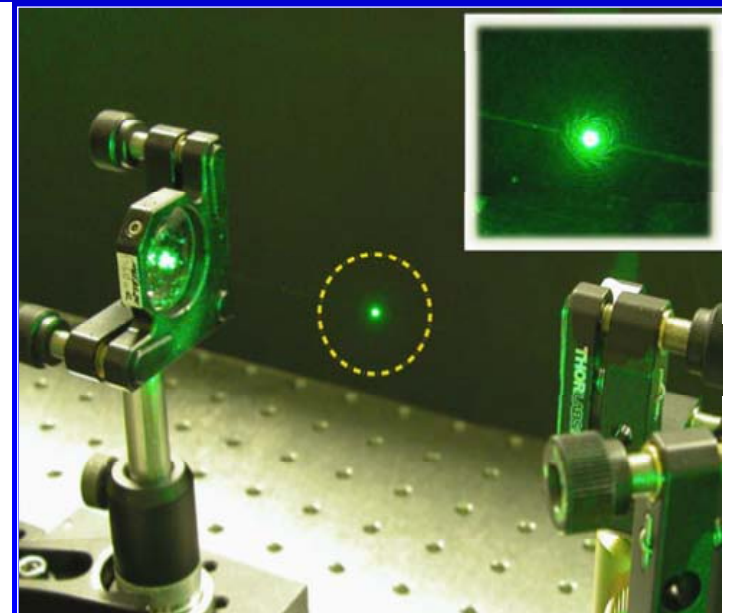
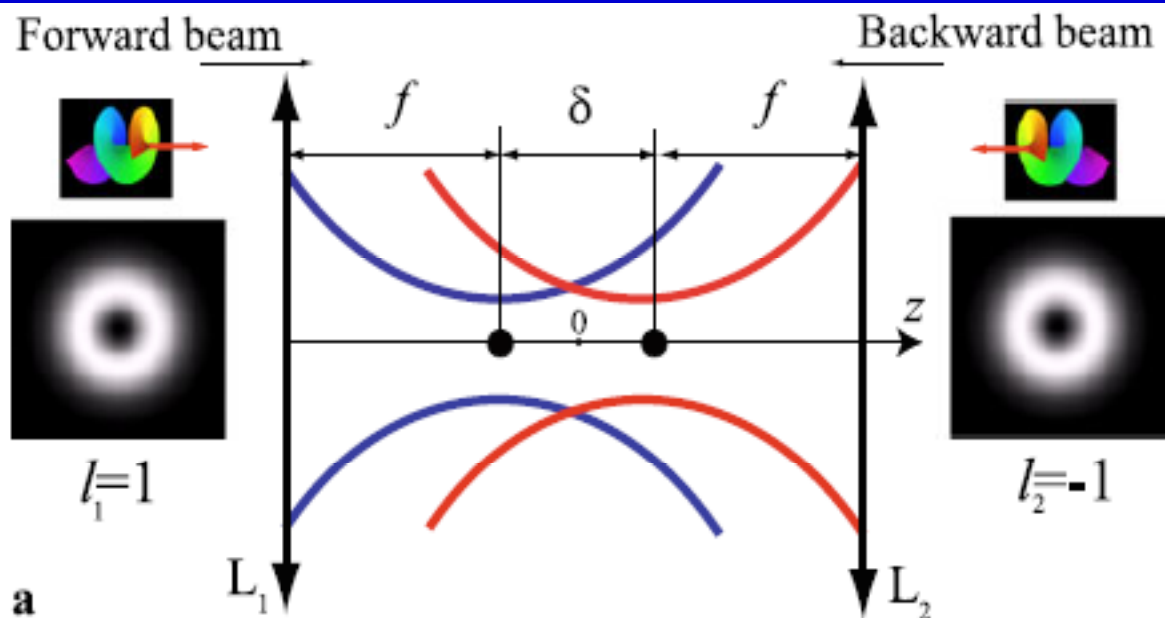


Photographs of the single-beam gradient-force optical trap of a glass sphere of $d = 5.0 \mu\text{m}$ in air. A trapping laser beam is irradiated perpendicularly to the plane of the photographs. (a) Trapped glass sphere indicated by the arrow. (b) The same trapped sphere, lifted by a vertical movement of the focus of the beam.

Optical vortex beams for trapping and transport of particles in air

V.G. Shvedov · A.S. Desyatnikov · A.V. Rode ·
Y.V. Izdebskaya · W.Z. Krolikowski · Y.S. Kivshar

Light-absorbing particles cannot be trapped by single-beam gradient force, but trapped by two optical vortex beams.



Thermal photophoretic force

□ Photophoresis - When a surface of an aerosol particle is heated nonuniformly by light, the surrounding gas molecules rebound off the surface with different velocities creating an integrated force on the particle.

Radiation pressure force exerted by a beam with power P ,

$$F_a = P/c,$$

The photophoretic force for particles with zero thermal conductivity,

$$F_p = P/(3v)$$

where c is the speed of light, and v is the molecular velocity.

$$F_p/F_a = c/(3v) \sim 6 \times 10^5$$

With $c = 3 \times 10^8$ m/s, $3v \sim 500$ m/s.

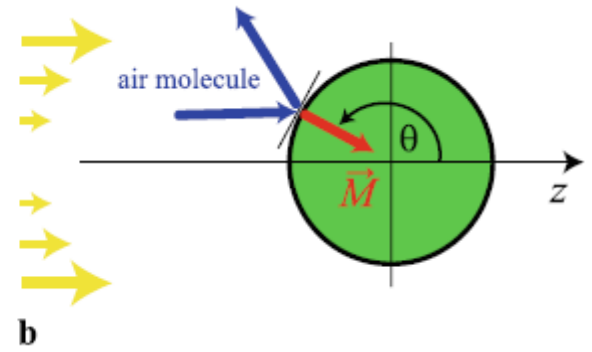
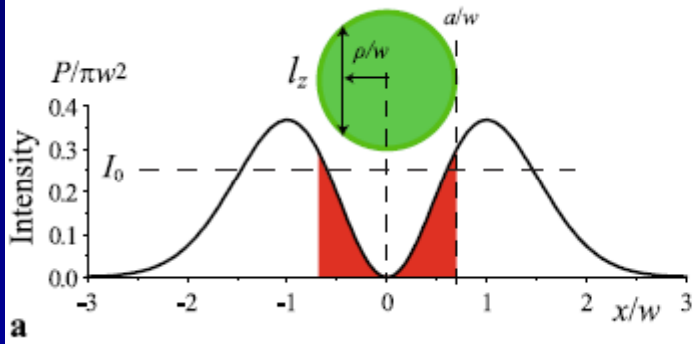
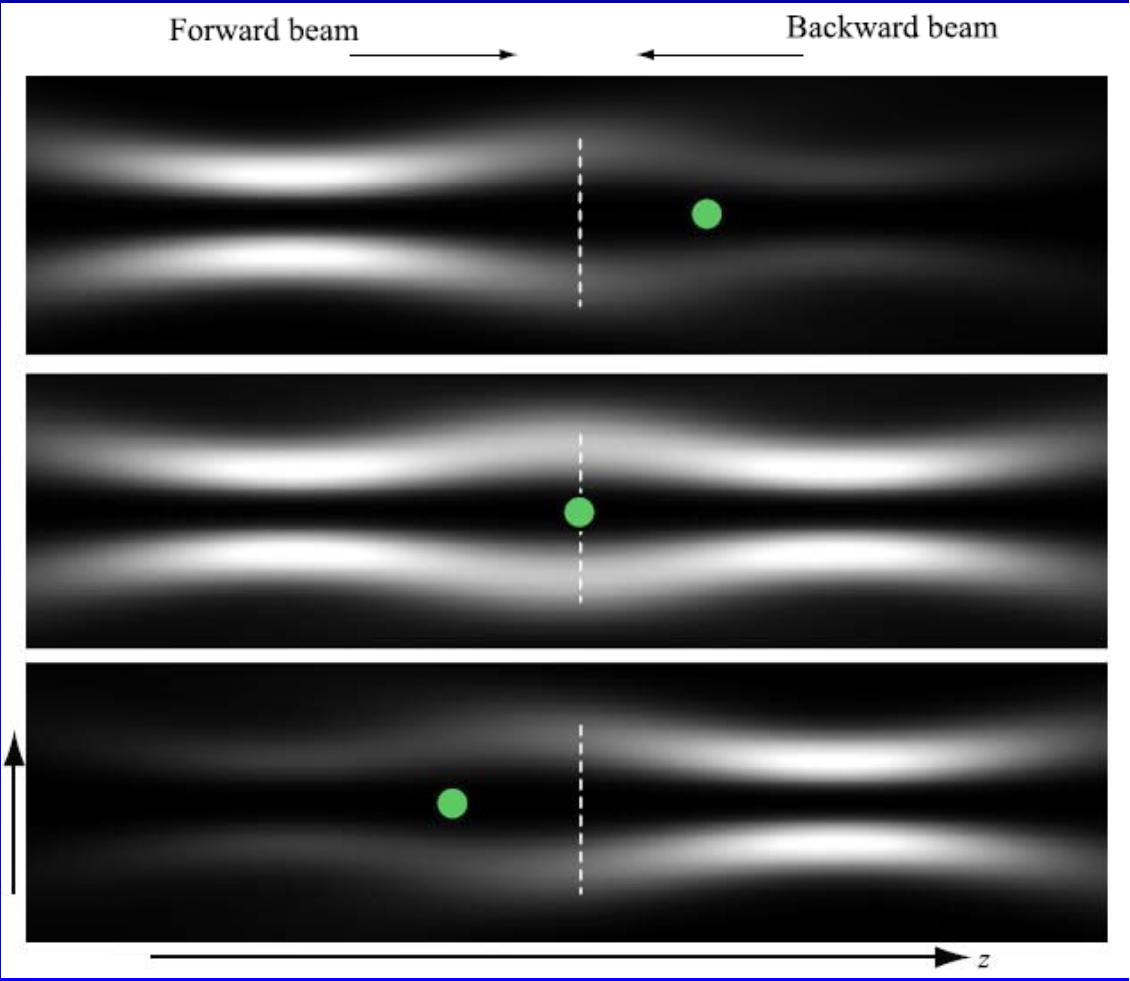


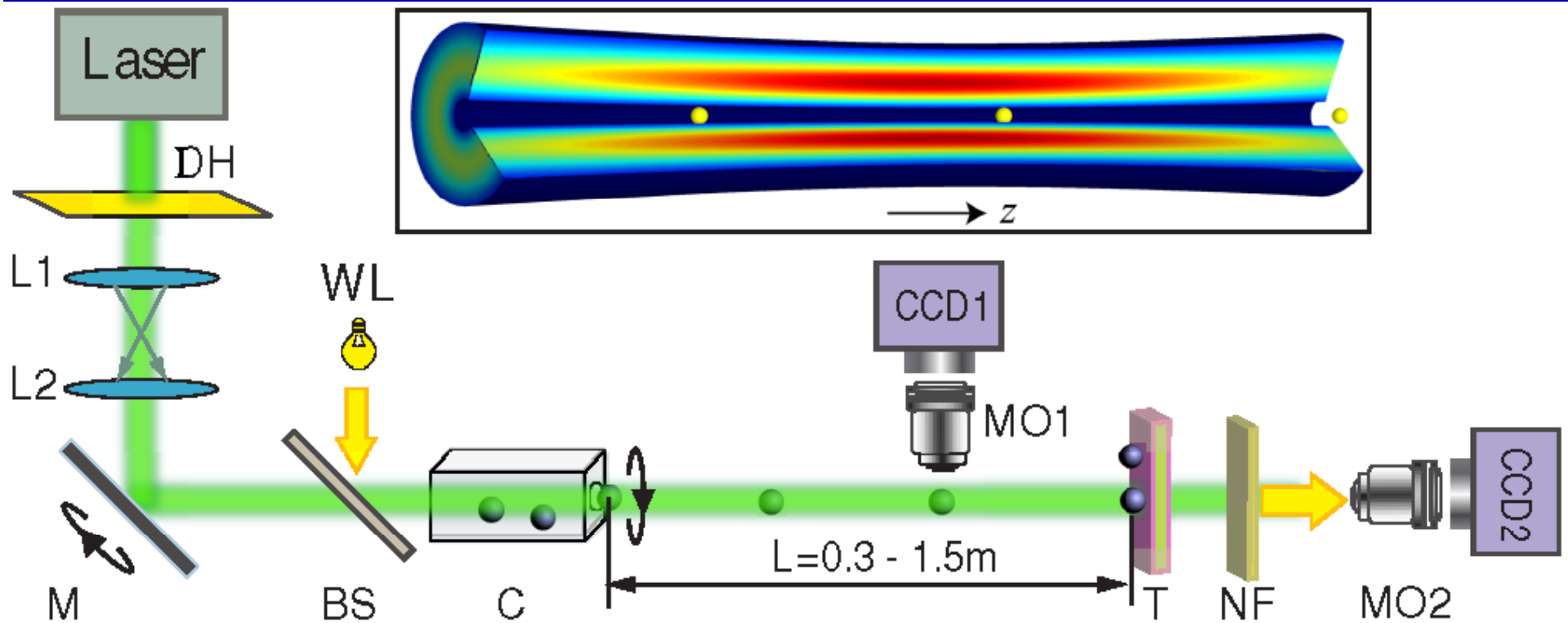
Fig. 3 a Vortex intensity cross-section; red-shaded is the part of a vortex beam illuminating particle (green sphere). b Transfer of a momentum (red arrow) from a gas molecule to a particle. c Stationary positioning of particle along optical axis by changing relative intensity of the beams.



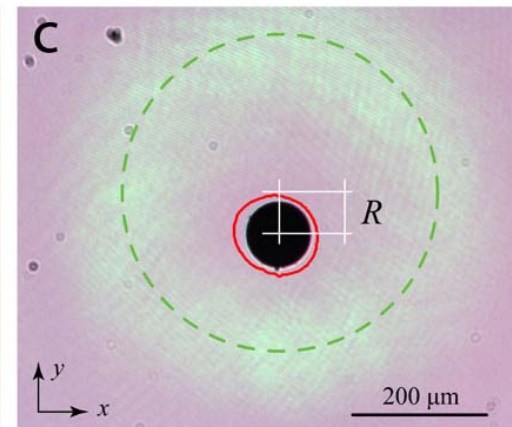
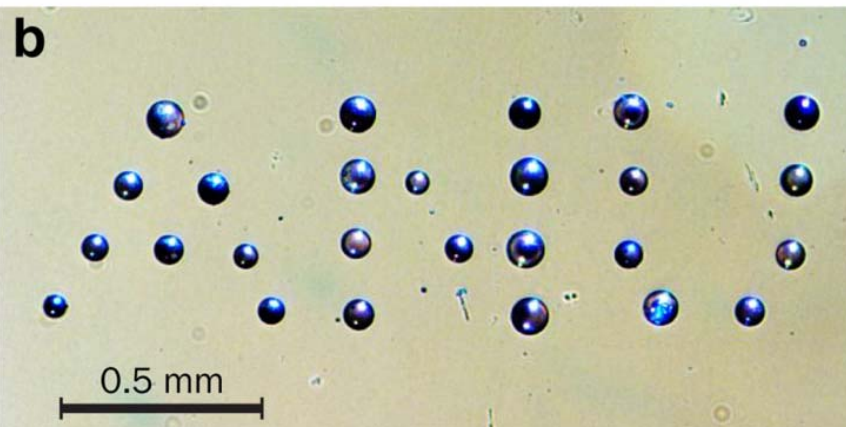
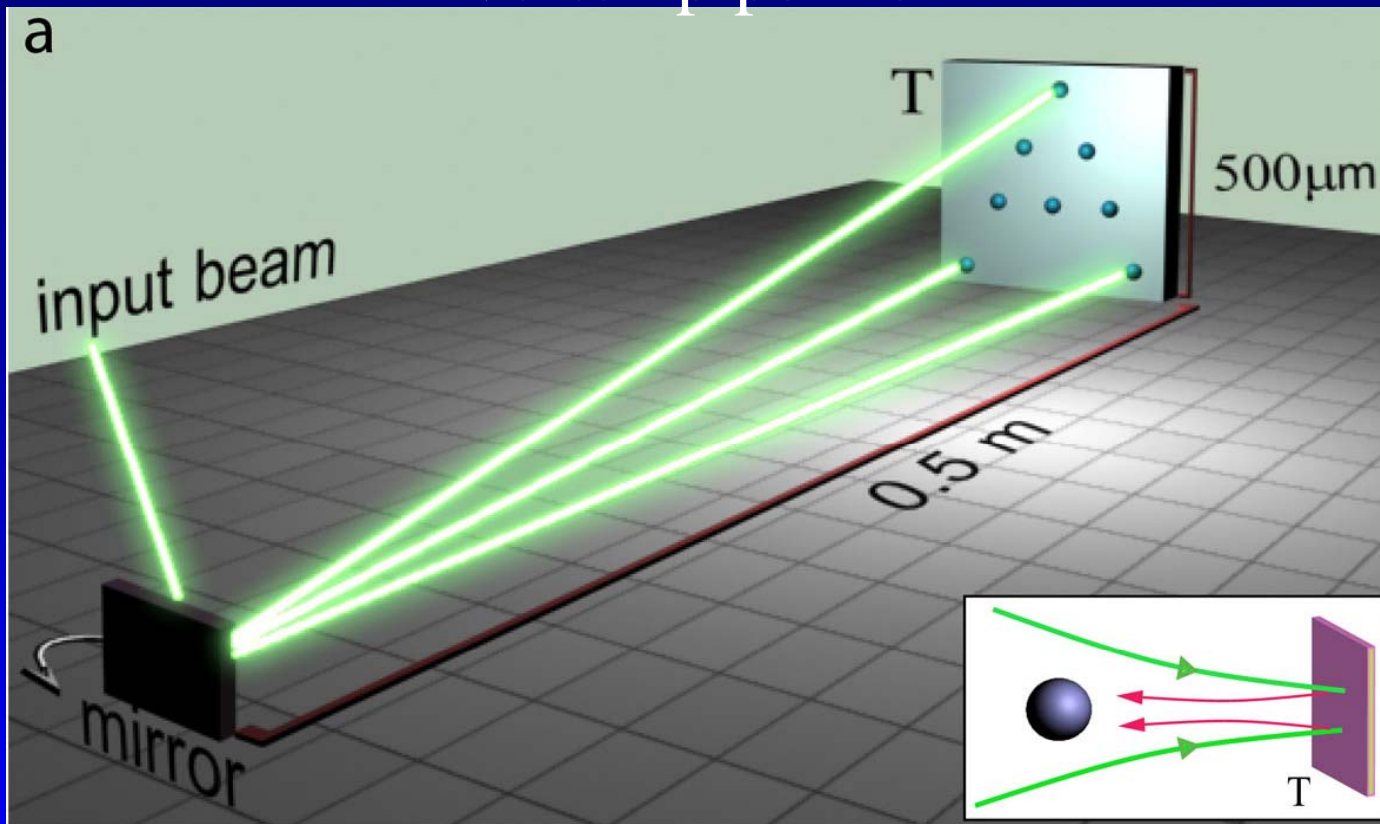
Giant Optical Manipulation

Vladlen G. Shvedov,^{1,2,3} Andrei V. Rode,¹ Yana V. Izdebskaya,^{2,3} Anton S. Desyatnikov,²
Wieslaw Krolikowski,¹ and Yuri S. Kivshar²

Optical vortex pipeline

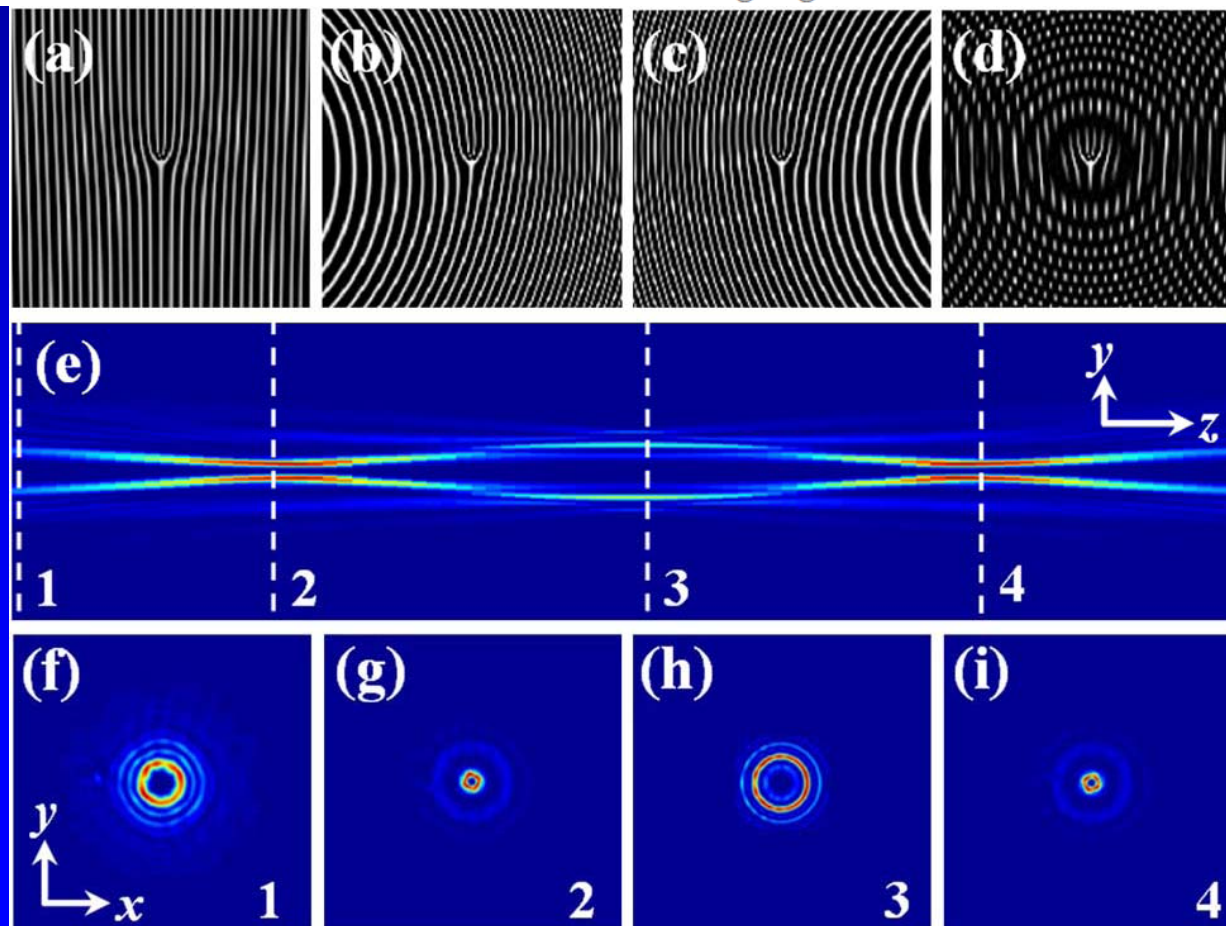


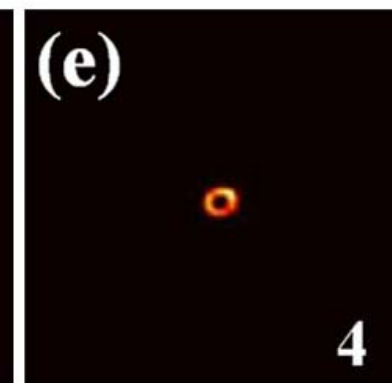
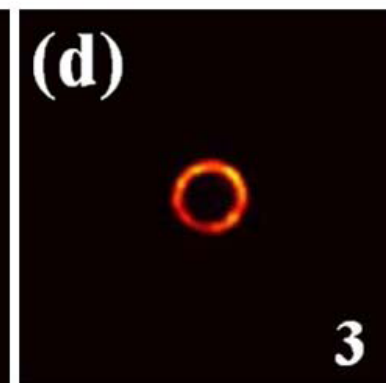
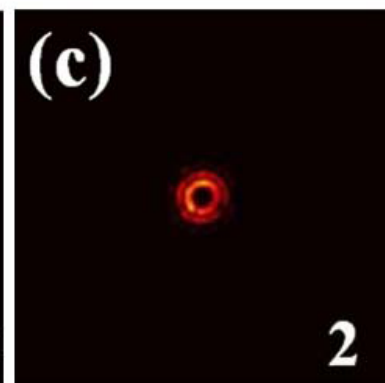
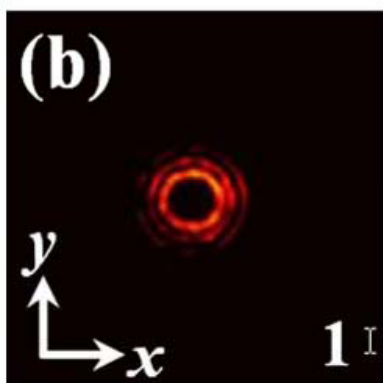
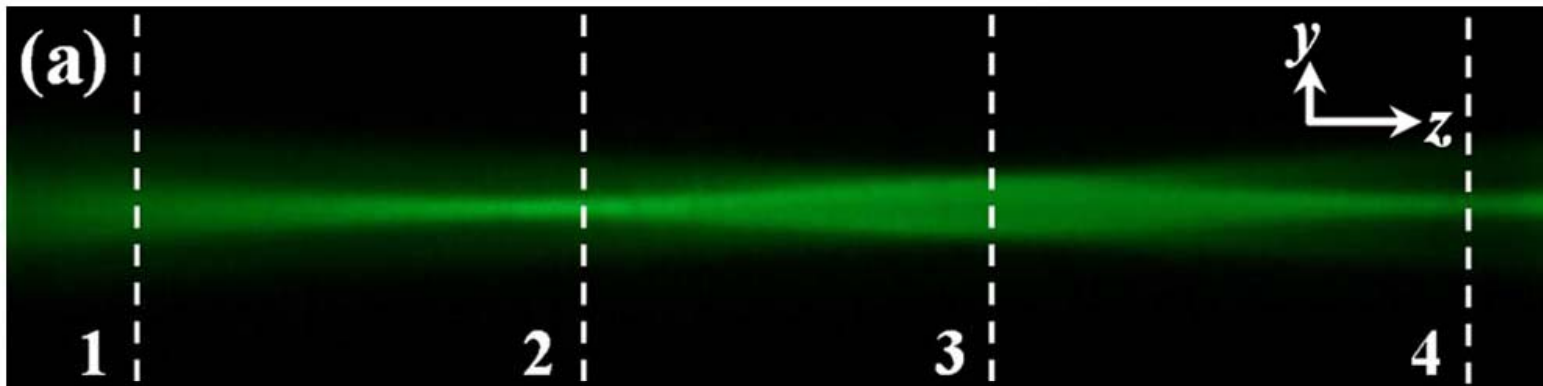
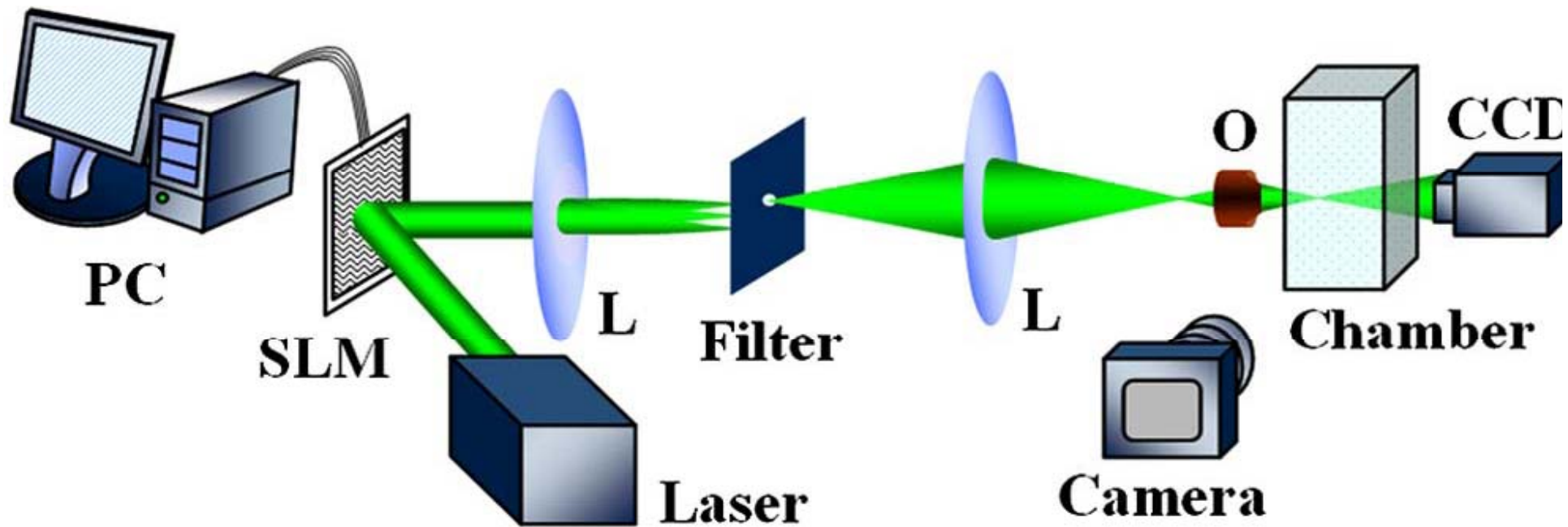
Remote manipulation of particles using the optical vortex pipeline

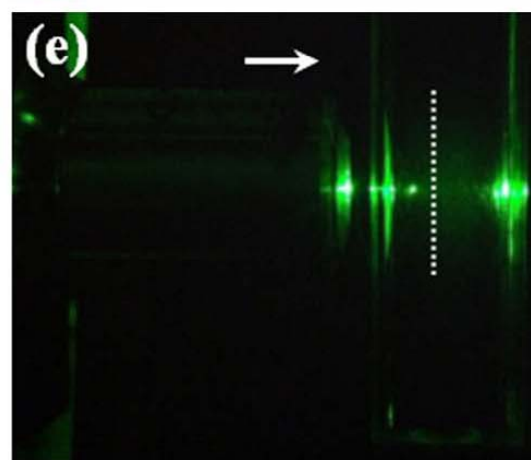
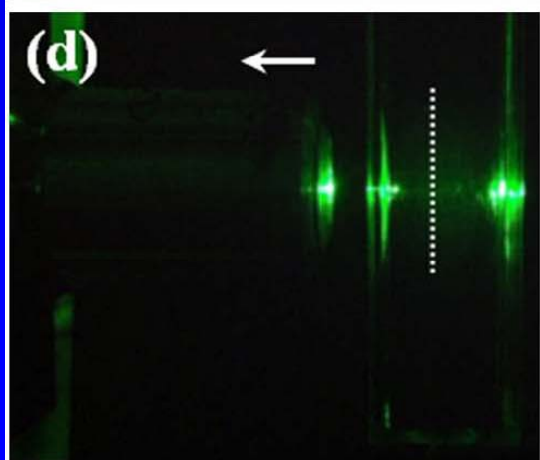
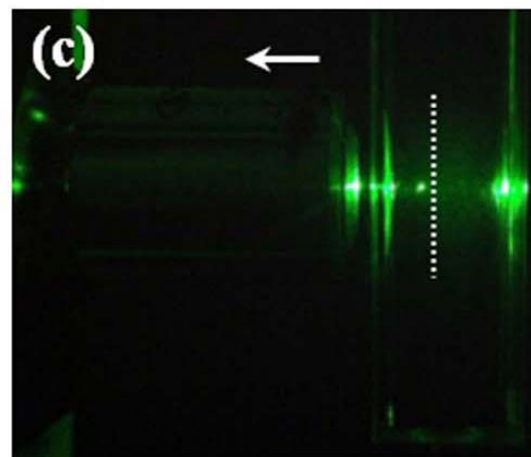
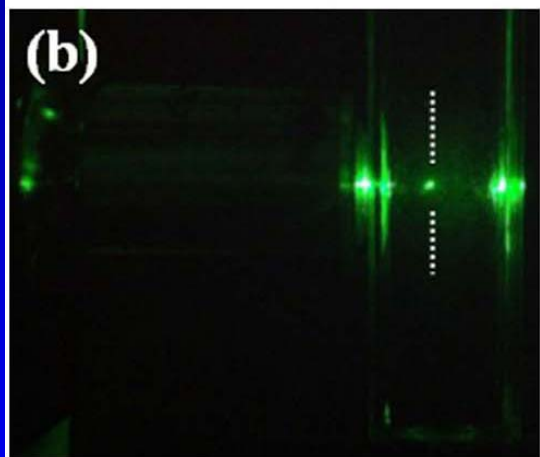
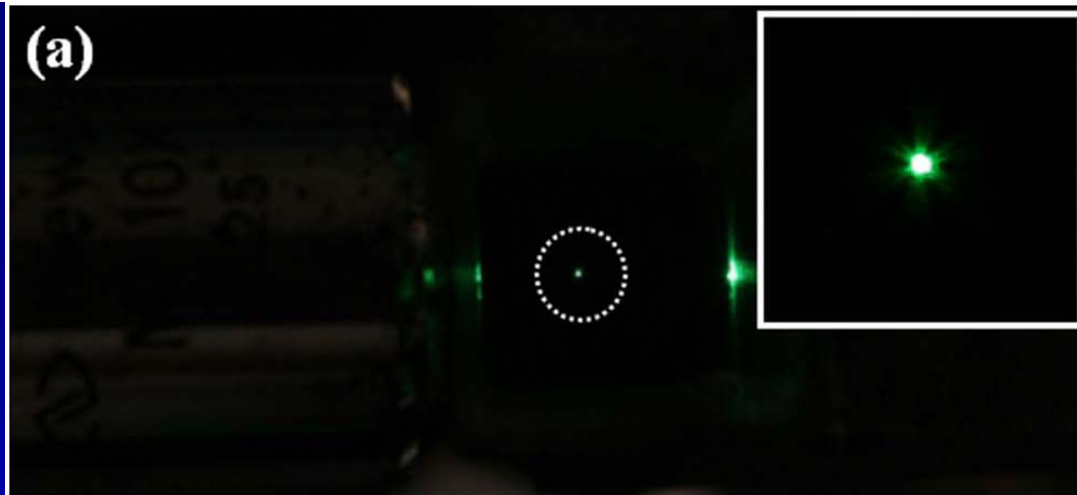


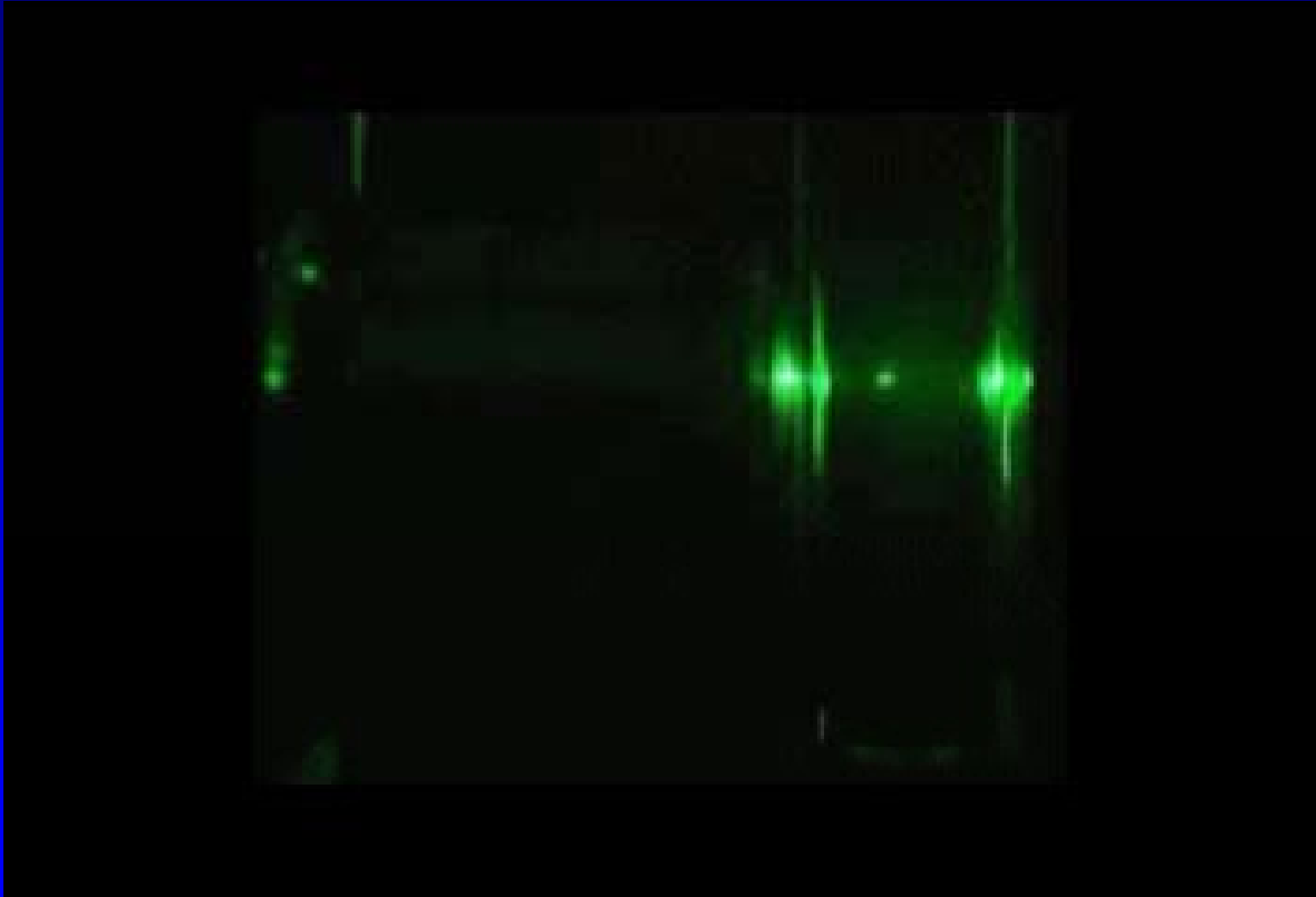
Trapping and transporting aerosols with a single optical bottle beam generated by moiré techniques

Peng Zhang,¹ Ze Zhang,^{1,2,3} Jai Prakash,¹ Simon Huang,¹ Daniel Hernandez,¹ Matthew Salazar,¹ Demetrios N. Christodoulides,² and Zhigang Chen^{1,4,*}









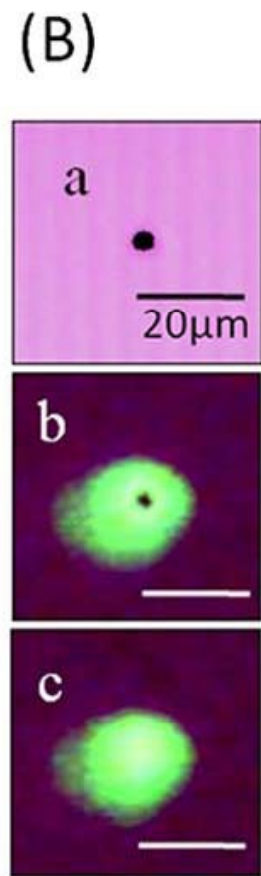
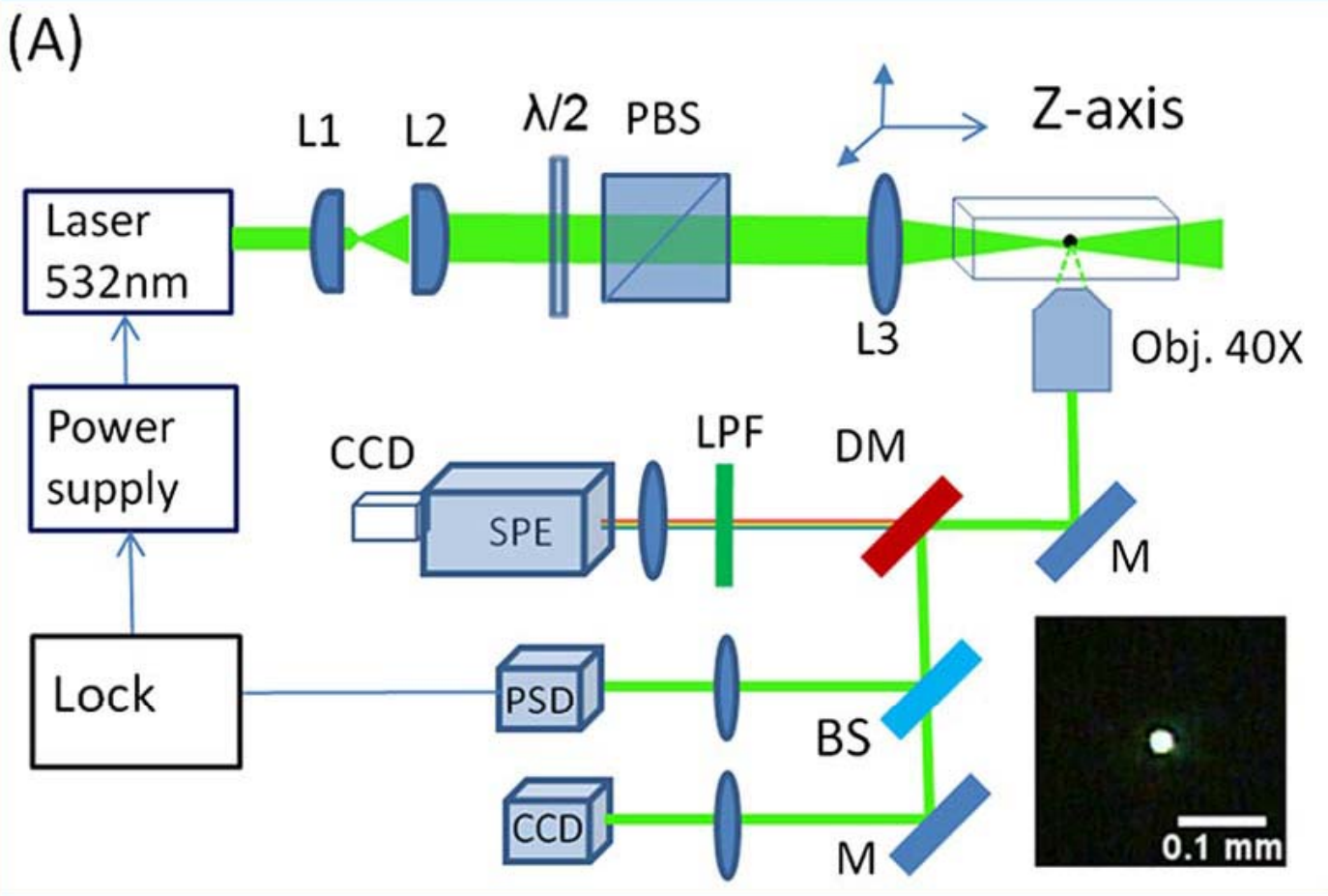
V

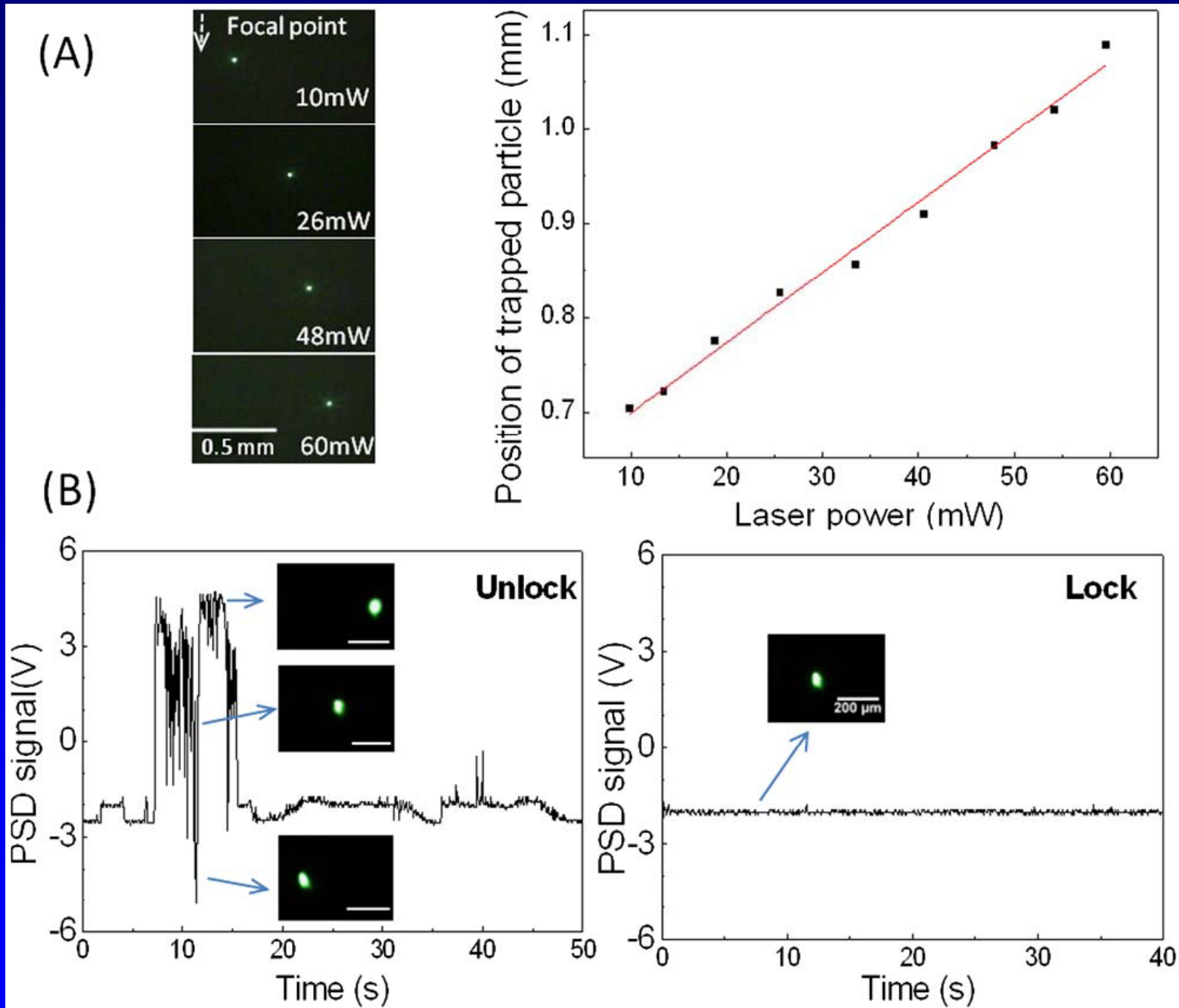
Measurement of Raman spectra of single airborne absorbing particles trapped by a single laser beam

Lin Ling and Yong-qing Li*

Department of Physics, East Carolina University, Greenville, North Carolina 27858-4353, USA

*Corresponding author: liv@ecu.edu





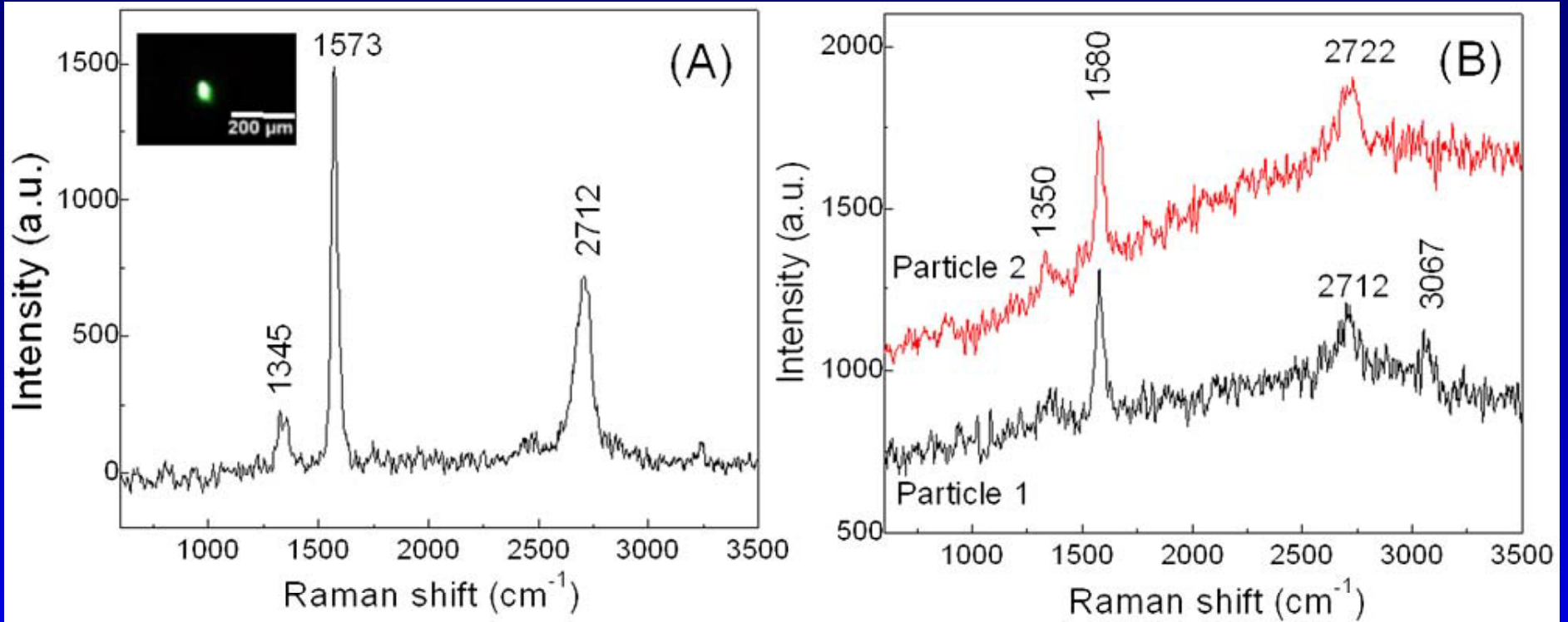


Fig. 3. (Color online) Raman spectra of optically trapped particles in air. (A) Carbon nanoparticle cluster: inset is the image of the trapped cluster and (B) two individual particles of ground pencil powder. The laser power of the input trapping beam was about 400 mW and the Raman acquisition time was 50 s.

Summary

We demonstrated a new method for optical trapping and Raman spectroscopy of micron-sized absorbing airborne particles using a single focused Gaussian beam.

A single Gaussian beam is used to trap single absorbing particles in air. We have actively stabilized the position of the trapped particles by controlling the laser power and then measured their Raman spectra. The position of trapped particles can be conveniently moved by several millimeters by adjusting the 3D position of the focused lens.

The manipulation of absorbing particles makes it convenient to image the trapped particles and measure their Raman spectra using a high throughput objective. This method may be applied for characterization and identification of single airborne particles in atmospheric and environmental sciences.

Further references for trapping in air

1. A. Ashkin and J. M. Dziedzic, 1971, Optical levitation by radiation pressure, *Appl. Phys. Lett.* **19**, 283-285.
2. R. Omori, T. Kobayashi, and A. Suzuki, 1997. Observation of a single-beam gradient-force optical trap for dielectric particles in air, *Opt. Lett.* **22**, 816-818.
3. S. Desyatnikov, V. G. Shvedov, A. V. Rode, W. Krolikowski, and Y. S. Kivshar, “Photophoretic manipulation of absorbing aerosol particles with vortex beams: theory versus experiment”, *Opt. Express* **17**(10), 8201 (2009).
4. V. G. Shvedov, A. V. Rode, Y. V. Izdebskaya, A. S. Desyatnikov, W. Krolikowski, and Y. S. Kivshar, Giant optical manipulation, *Phys. Rev. Lett.* **105**, 118103 (2010).
5. P. Zhang, Z. Zhang, J. Prakash, S. Huang, D. Hernandez, M. Salazar, D. N. Christodoulides, and Z. Chen, “Trapping and transporting aerosols with a single optical bottle beam generated by moiré techniques”, *Opt. Lett.* **36**, 1491 (2011).
6. Z. Zhang, D. Cannan, J. Liu, P. Zhang, D. N. Christodoulides, and Z. Chen, “Observation of trapping and transporting airborne absorbing particles with a single optical beam”, *Opt. Express* **20**, 16212 (2012).
7. L. Ling and Y.-q. Li, “Measurement of Raman spectra of single airborne absorbing particles trapped by a single laser beam”, *Opt. Lett.* **38**, 416-418 (2013).