Proceedings of the 6th International Symposium
on
Advanced Nuclear Energy Research
—INNOVATIVE LASER TECHNOLOGIES IN NUCLEAR ENERGY—

FUNDAMENTAL STUDY ON LASER MANIPULATION OF CONTAMINATION PARTICLES WITH DETERMINING SHAPE, SIZE AND SPECIES

Isao SHIMIZU and Takatsugu FUJII

Department of Mechanical Engineering
Ibaraki College of Technology
866 Nakane, Katsuta-shi, Ibaraki-ken 312 Japan

It has been desired to eliminate or collect the contamination particles of radioisotope in each sort of species or shape and size non-invasively. The shape and size of particle can be determined from the shape and distribution of diffraction pattern of particle in the parallel laser beam, the species of particle can be discriminated by the fluorescence from resonance of laser beam, or by the laser Raman scattering, and the particle suspended in the air or falling down in a vacuum can be levitated against the gravity and trapped by the radiation force and the trapping force of the focussed laser beam in the atmosphere or in a vacuum. For the purpose of the non-invarsive manipulation of contamination particles, the laser manipulation technique, image processing technique with Multiplexed Matched Spatial Filter and the determination technique of laser Raman scattering or fluorescence from resonance of laser light were combined in the experiments. The shape, size and species of particles trapped in the focal plane of focused Ar laser beam can be determined simultaneously and instantaneously from the shape and intensity distributions of diffraction patterns of the particles in the irradiation of parallel coherent beam of He-Ne laser, and fluorescence from the resonance of YAG laser beam with variable wave length. In this research, a new technique is proposed to manipulate non-invasively the contamination particles determined with the shape, size and species in the atmosphere or in a vacuum, by laser beam.

Keywords: Laser manipulation, Radiation pressure, Trapped particles, Non-invasive elimination, Small particles, Radioisotope, Shape and size of particles, Diffraction pattern, Smoke particles

1. INTRODUCTION

The radiation force of laser beam can be used to manipulate small particles suspended in the air in the clean room. It seems that the radiation force of laser beam is suitable to eliminate non-invasively contamination particles of radioisotope. Therefore, the behavior of particles in the laser beam is investigated theoretically and experimentally [4].
The simultaneous measurement of shape and size or species of particles trapped at the focal plane of lens in the incident laser beam has been desired to analyze the behavior of particles in each sort of shape and size or species. The non-invasively manipulating or

eliminating techniques for the small particles of radioisotope suspended in the air is proposed as follows.

2. INVESTIGATION ON THE MANIPULATION OF PARTICLES AND OBSERVING THE BEHAVIOR OF SMALL PARTICLES MOVED BY RADIATION FORCE

2.1 Theoretical and experimental study on radiation pressure

Entering into the laser beam, the particles are exposed to radiation pressure by photons. The magnitude and direction of radiation force acting on the particles are generally deduced from the conservation law of momentum being kept in the system of the particle and photons as shown in Fig. 1. Nevertheless, when the particle is put in an arbitrary position in the laser beam of which distribution is Gaussian for intensity, in order to know quantitatively the magnitude of radiation force for the particle, it is needed to calculate the magnitude of radiation force being induced from the intensity distribution of the light scattered from the particle in the position[1]. Recentry, it becomes possible to calculate the Mie scattering intensity distribution from a particle put in the incident laser beam having Gaussian distribution of intensity, by micro-computer [2]. The coordinate system shown in Fig. 2 is used for calculation. In the results of calculation, the radiation force for the particles always acts toward the progressive direction of incident laser beam, anti-progressive force of radiation could not be found in anywhere [3]. As the size of particles became larger in comparing with the diameter of beam waist of the incident beam, it became clear that the radiation force for the particles decreased at the focal point because the diameter of particles protruded from the beam waist. The radiation force acting in the direction of lateral axis(x direction) acts toward the high-intensity region as the restoring force to the center of the laser beam when the refractive index of a particle is greater than that of the surrounding medium.

Experimental setup and outline of experiments are as follows. The laser beam is expanded ten times by beam expander B.E. as shown in Fig. 2. The enlarged and parallel laser beam is reflected by the mirror setted on a Galvano-scanner, and is focussed by convex lenses having focal length, f=40 mm - 70 mm. We can observe the behavior of particles in the laser beam from X and Y directions which are perpendicular to the laser beam axis Z with camera and video camera respectively. An Ar ion laser was employed as a light source of which the output power was 1.2 W on wave length λ=488 nm. The waist diameter of the focussed laser beam, $2w_0$ is derived for $w_0 = 4\lambda f/3\pi D$, where D is the diameter of pararell beam. From this relation, we can get the value $2w_0$=1.7 μm, for following values, f=50 mm, D=12.5 mm. The refractive index of polystyren particle is m=1.592.

The influence of the disturbance from air flow and turbulence was avoided by surrounding the focal point of laser beam with enclosure made of glass chamber in the experiments.

2.2 Behavior of small particles moved in the air by the force of laser beam

Polystyrene particles having uniform size(d= 1 μm, or 5, 10, 15, 20 μm) being sprayed in the glass chamber by a ultrasonic humidifier, the monodisperse polystylen particles(d=1.0 μm) mixed in the atmosphere enter into the laser beam, and are trapped near the focal point as shown in Fig.3(a) or are sent flyingto the progressive direction of the incident beam as shown in Fig.3(b) and 3(c). The laser beam(laser power 0.4 W) was progressive from left to right hand side in the photographs of Fig.3.

The experimental results showed that the trapped particles were able to be manipulated three - dimensionally, easily and steadily by the three dimensional scanning of the laser beam. The loci of particles manipulated hand-operatedly to the X direction were shown in Fig.4 as an example. In this experimental conditions, the values were, laser power 0.4 W, f=40 mm, d=5 μm.

Smoke particles of incense are sent flying to the anti-progressive direction of incident laser beam at the all positions in the laser beam as shown in Fig.5. The loci of image displacements of smoke particles, at the slow speed are shown in Fig.5(a),(b), and at the high speed are shown in Fig.5(c),(d), respectively. The size of smoke particles are estimated under 0.1 μm in diameter. At the present, we can not clarify the reasons whey the smoke particles are sent flying to the anti-progressive direction of incident laser beam at all positions.

3. SIMULTANEOUS DETERMINATION OF THE SHAPE, SIZE AND SPECIES OF SMALL PARTICLES

The shape and size of particles are presumed from the forward scattering intensity distribution at the small scattering angles (or, diffraction pattern). And, the shape and size of particles are discriminated by the holographic filter (Matched Spatial Filter) made by the diffraction pattern scattered from reference shape of particles. In Fig.6, when some particles enter into the frontal forcal plane of the Fourier transform lens at the axis of parallel coherent incident beam, the diffraction patterns can be observed at the back focal plane of the lens. In Fig.7, when monodispersed polystyren particles having size d=10 μm, and d=19.5 μm in diameter are set at the frontal forcal plane P_1, the diffraction patterns appearing at the back focal plane P_2 of the lens are shown respectively. In this method, if the diffraction pattern of a particle having any shape can be simulated in calculation, or if the shape of particle can be recognized beforehand and the diffraction pattern of the shape can be known, the shape of particle can be discriminated from the diffraction pattern at the back focal plane of the Fourier transform lens.

When some particles are trapped by the Ar ion laser beam focussed at the plane P_1 perpendiculary to the axis of the He-Ne laser beam, the diffraction patterns can be observed at the back focal plane P_2. In Fig. 8, laser manipulating system of small particles using Ar ion laser with determining the shape, size and species of particles simultaneously. The dark field observing system of diffraction pattern using He-Ne laser and optical system is used as shown in Fig. 8, because the trapped particle is too small so that the intensity of the diffraction pattern is week.

In Multiplexed Matched Spatial Filtering method, setting a reference shape of particle on the frontal focal plane P_1 of lens L_1 being put in the coherent pararell incident laser beam, making the diffraction pattern on the back focal plane P_2, interfering the diffraction pattern with the reference beam on the P_2, the hologram is made on the photoplate being put in the plane P_2. When particles pass through the P_1 plane, the diffraction patterns from the particles are discriminated by the hologram being put in plane P_2. If the particles having the same shape as the reference shape are there, the auto-correlation peaks can be observed on the back focal plane P_3 of inverse Fourier transform lens in the back focal plane of inverse Fourier transform lens.

For the measurement of species of the trapped particles and gasses, using laser light of the tunable YAG laser system composed of the optical parametric generation and the pulsed YAG laser, the fluoresence technique or Raman scattering technique can be applied.

4. PROPOSAL OF NEW TECHNIQUE MANIPULATING OR ELIMINATING SMALL PARTICLES SUSPENDED IN THE AIR WITH DISCRIMINATING THE SORT OF THE SHAPE, SIZE OR SPECIES

Smoke particles of incense can be eliminated by the Ar laser beam of 1.0 W. By Ar laser beam, sending the smoke particles to the anti-progressive as shown in Fig. 9, the smoke particles can be collected on the glass plate. The non-invasively manipulating or eliminating technique for the small particles of radioisotope suspended in the air has been developed using those technique.

The manipulation technique for the large particles with determining the shape, size and species is proposed as shown in Fig. 8.

5. CONCLUSION

It was clarified that the trapped particles of which diameter were over 1 μm, by radiation force, could be steadily manipulated by the scanned laser beam in the horizontal plane. It was recognized that there were some possibility, which could remove and eliminate particles of which diameter were over 1 μm by horizontally scanning direct beam of Ar laser, and which could separate the particles in each shape or size with discriminating technique analyzing diffraction pattern from particles. To manipulate the particles, it was clarified that the Gaussian intensity distribution of the laser beam had to be definitely preserved in the laser barrier. A new manipulation technique for the large particles with determining the shape, size and species was proposed.

In experiments, it was recognized that smoke particles of which diameter were under 0.1 μm were sent flying to the anti-progressive direction of incident laser beam at all position. A new technique has been proposed to eliminate or collect the small particles like as smoke particles or radioisotope particles suspended in the air.

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ACKNOWLEDGEMENT

Some parts of this work were financially supported by A Grant in Aid for Scientific Research from the Ministry of Education, Science and Calture in Japan; Grant in Aid for General Scientific Research (B): (project number 05452224), Separation of small particles in each shape and size by laser manipulating technique with optical neuro- discriminating technique, and supported by A Grant under the Monbusho International Scientific Research Program (University to University Cooperative Research): (Project number 03045049), Research on manipulation of particles by laser beam.

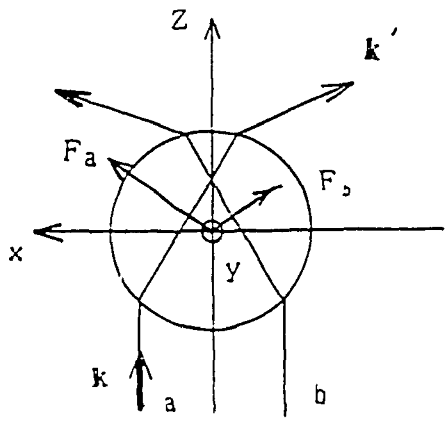


Fig. 1 The schematic diagram explaining the radiation force deduced the conservation law of momentum being kept in the system of the particle and photons

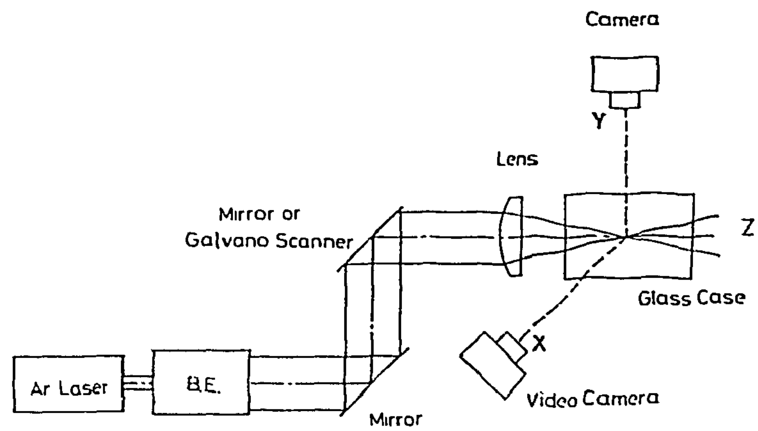
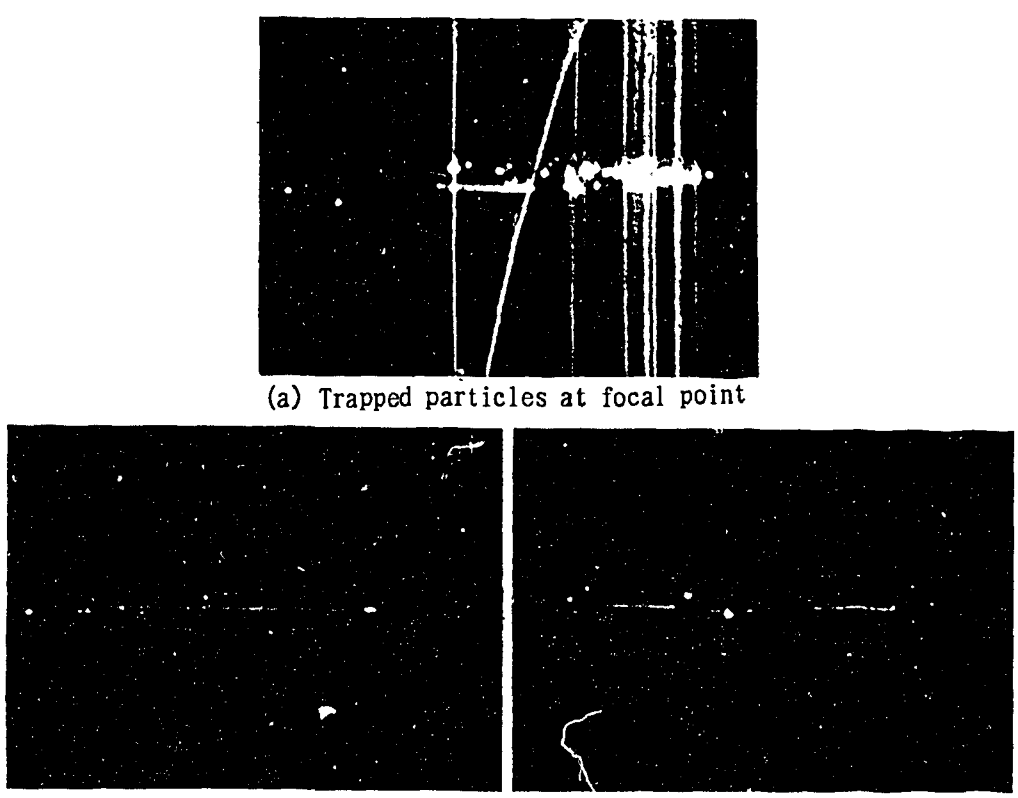


Fig. 2 schematic diagram of apparatus manipulating particles by laser beam



(a) Trapped particles at focal point

(b) Moving particles —>

(c) Moving particles —>

Polysterene particles (d=1.001[μm]) —>
Laser beam

Fig. 3 The behavior of particles trapped or removed the laser beam

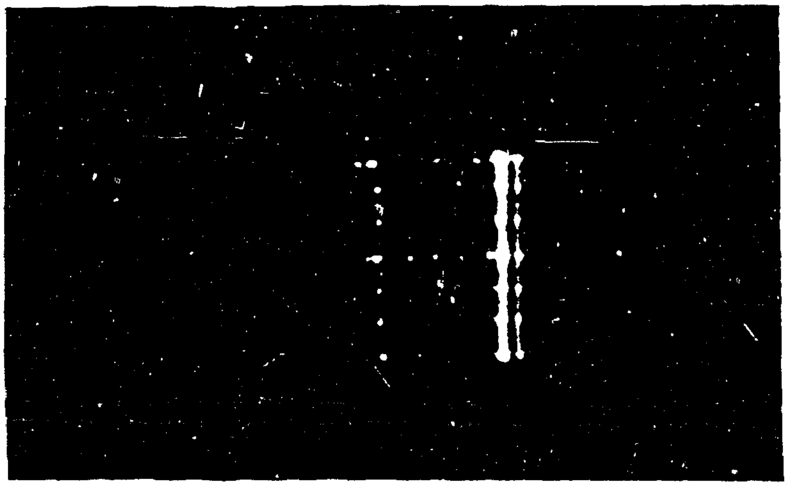
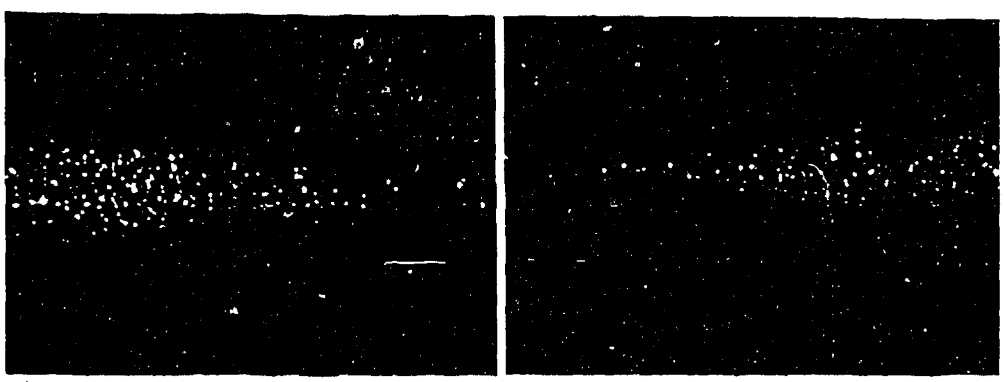
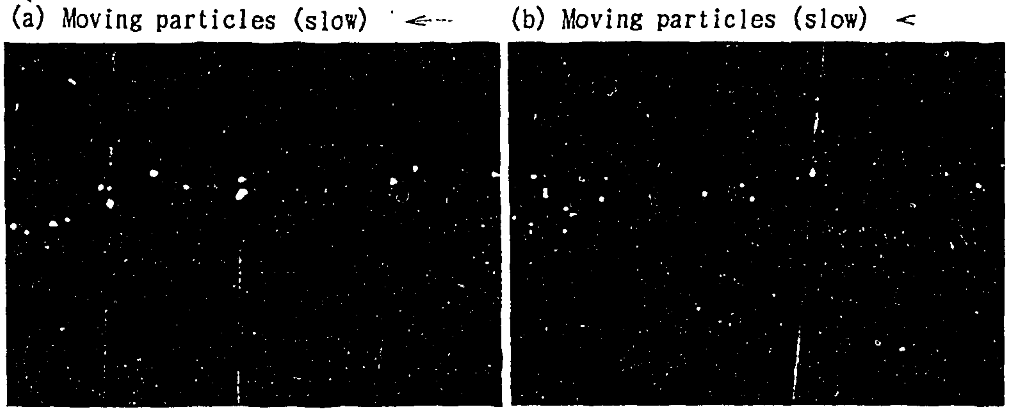


Fig. 4 The loci of particles manipulated by laser beam, in X direction



(a) Moving particles (slow) ←

(b) Moving particles (slow) ←



(c) Moving particles (rapid) ←

(d) Moving particles (rapid) ←

Smoke particles of incense

Laser beam →

Fig. 5 The loci of image displacements of smoke particles in the laser beam

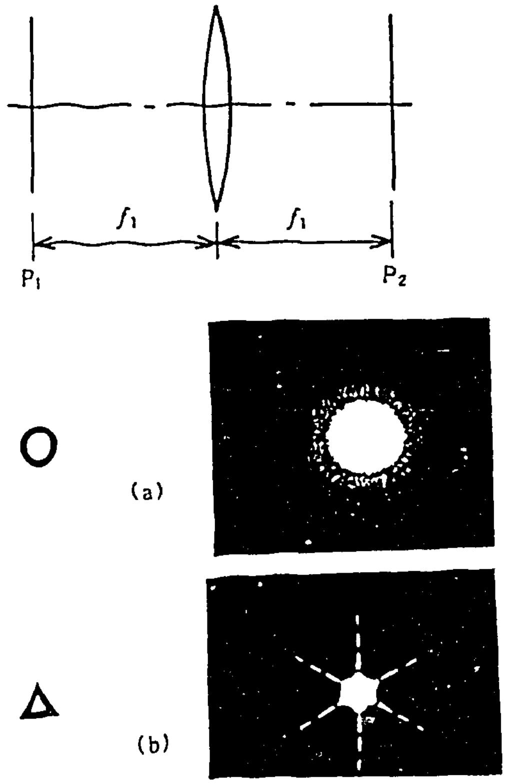
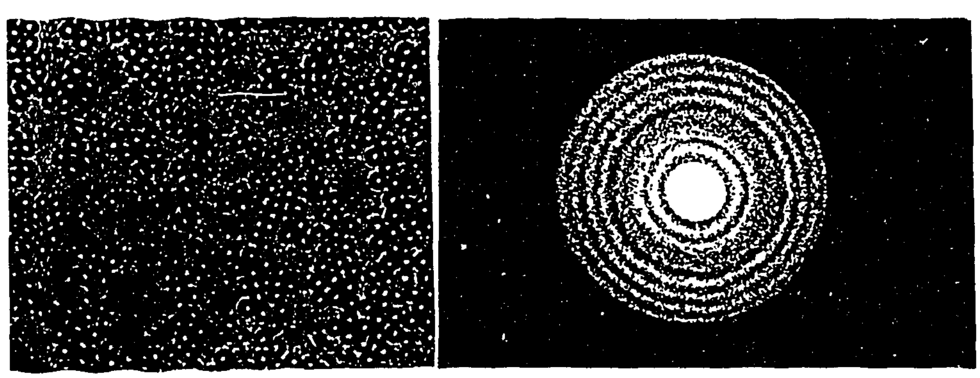
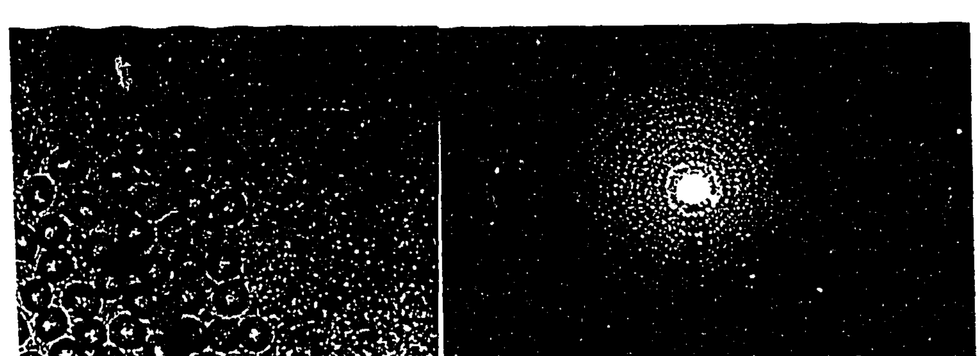


Fig. 6 Optical system observing the diffraction pattern from the particles



Particles (d=10.35[μm]) Diffraction pattern



Particles (d=19.5[μm]) Diffraction pattern

Fig. 7 Examples of diffraction pattern obtained from monodispersed spherical particles

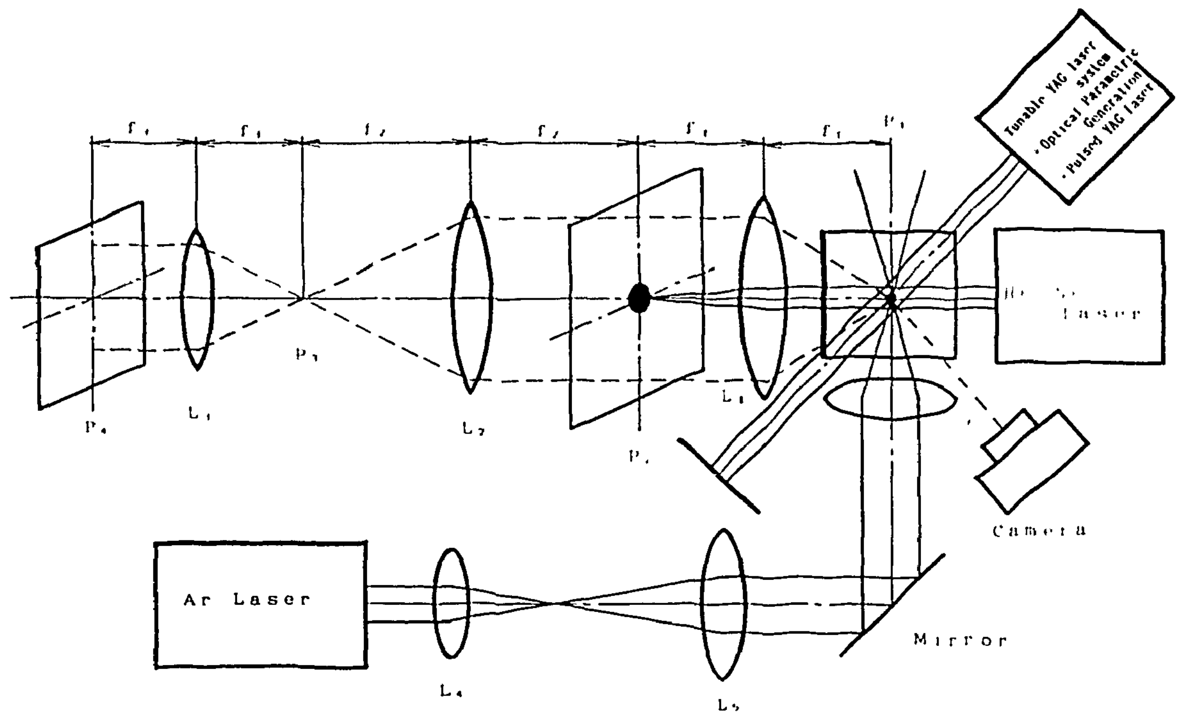


Fig. 8 Laser manipulating system with determining the shape, size and species of small particles

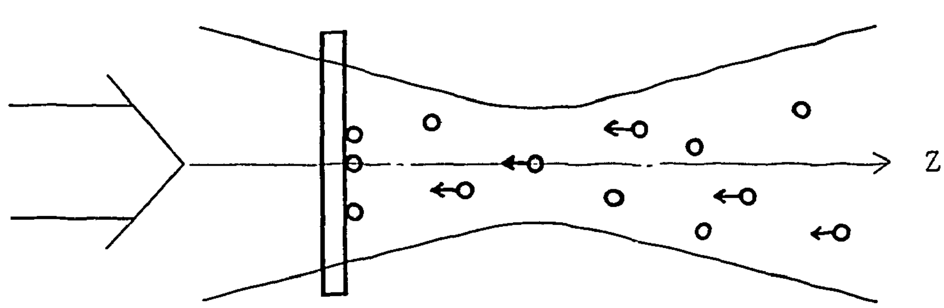


Fig. 9 Schematic diagram of collecting system of nano-meter particles in the air