NEW MICRO-ASSEMBLY TECHNIQUE OF THREE DIMENSIONAL MICRO-STRUCTURE BY YAG LASER BEAM

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1. Introduction

In recent years, the realization of micro-machine and micro-device with elements having various functions integrated becomes more and more necessary. If a new micro-machining technique which can manufacture material and shape at the same time is developed, the highly functional parts with less space can be expected. In this research, a new concept is considered by arranging the fine particles in three dimension according to the design of material and shape of the parts, and then sintering to strength the structure. However, to fulfill this task, the three dimension manipulation and micro-assembly technique of fine particles is indispensable. The laser trapping technique was suggested to manipulate fine particles in water with optical radiation pressure by Ashkin in 1970[1]. Since the manipulation is non-contact, the following advantages can be obtained: 1) Complex manipulation with high degree of freedom. 2) High speed manipulation without vibration. 3) Manipulation of multiple particles at the same time. On the other hand, the manipulation is considered difficult in the air because the surface tension is very big between the base plate and fine particles. However, considering the environment of micro-machining, the manipulation in the air is desirable to meet the requirements of high degree of freedom and stability. Hereby, this research proposed a new method on trapping the fine particles in the air and developed a new micro-machining technique by assembling three dimensional micro-structure from fine particles with laser beam.

2. Experiments on Trap of Fine Particles with Laser Beam

2.1 Trapping principle of fine particles with optical radiation pressure

The generation of optical radiation pressure can be explained by geometrical optics in case the optical wavelength is shorter than the diameter of fine particle to be trapped[2]. The generation of radiation pressure with an optical beam going through a fine particle is shown in **Figure 1**. When beam "a" goes into a fine particles, an optical radiation pressure "Fat" happens at the orthogonal direction of the interface. Then, when the beam goes out from the fine particle, the optical radiation pressure "Fa0" happens. The total force is "Fa". As for the beam "b", force "Fb" happens. The total force "F" of "Fa" and "Fb" is in the direction which always makes the center of fine particle according to the focal point of laser beam. Hence, the trapping of fine particles with laser light becomes possible. Shown in **Table 1**, the optical radiation pressure acting on silica fine particles caused by YAG laser light were calculated. Silica fine particles are transparent for YAG laser light, and laser light irritates from the upper of fine particles which are put on the optical axis. In case the position of focal point is from the upper part of fine particles to the lower part of particles, the calculation result is shown in **Figure 2**. Axis Z illustrates the position of focal point (Z=r/R, r means the distance between center of particle and

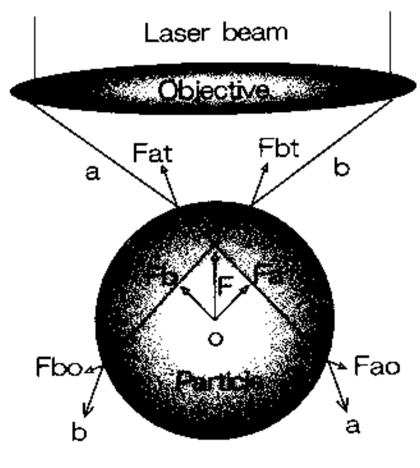


Fig.1 Qualitative view of particle trapping

focal point , R means the radius of particle), where +1.0 and -1.0 mean the top and bottom of fine particles respectively. Axis X shows the force acted on silica fine particles with the gravity force included. On this axis, the minus value means the force points downwards and the plus value means the force points upwards. When the output of laser is 14mW and focal point is on the upper part of fine particle, the total force from two directions offsets. When focal point is set at Z=0.75 with an output of 20mW, it is calculated that silica fine particles can be levitate into the air with optical radiation force.

Table 1 Conditions of calculation

YAG laser power	~20mW
Polarization	Circularly polarized light
Objective	N.A.=0.8
Particle	SiO_2(ϕ 8.0 μ m)
Refractive index	n=1.4
Enviroment	Air
Refractive index	n=1.0

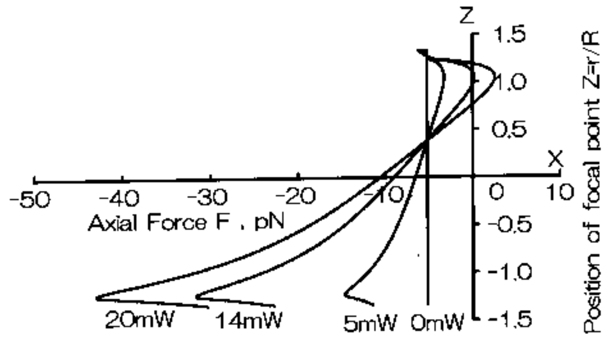


Fig.2 Relation between axial force and focal point

2.2 Experimental apparatus

The configuration of experimental system is illustrated in **Figure 3**, It is mainly consisted of three parts, laser oscillator, beam scanner and light accumulating part. The details of each are as follows:

1) Q-switched YAG laser (Lee Laser 818TQ, λ=1.06μm, maximum output 18W, beam Mode TEM_{00}) is applied in Laser oscillator.

2) Laser beam scanning part is constructed by two pieces of galvano mirror to realize horizontal laser scanning on X-Y surface which is orthogonal to optical axis. It is possible to scan the laser beam focal pointed by objective with high speed and at a resolution of 0.17μm.

3) Microscope is applied in the light accumulated part (Nikon X2-TI-EPI), YAG laser beam irradiates into the microscope, with the optical axis being the same as that of illumination. The bright field objective (CF IC EPI Plan × 50) is utilized. The aberration between visible light and YAG laser light has been removed through modification. The fine particles are observed in three-dimension space with CCD cameras arranged on the upper and side locations.

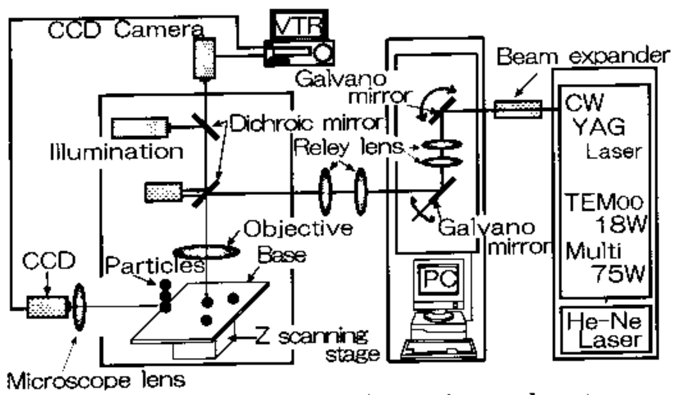


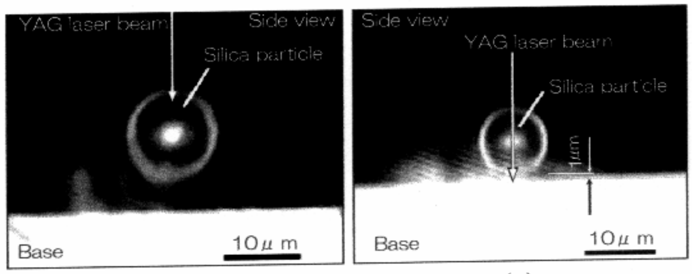
Fig3. Configuration of experimental system

2.3 Experiments on trap of fine particles

The trapping experiments were conducted in the air. The experimental results showed the output of laser must be more than 2W, which is 2 digits larger than that of calculation. It is supposed that the reason lies on the attractive force between the base plate and the fine particle caused by the moisture in the air. To overcome this force instantly, it is necessary to raise the peak output of laser light. Hereby the experiment was conducted by using Q-switch, whose condition is shown in **Table 2**. The focal point was set at the upper part of the fine particle. The experimental result showed that it is possible to trap a fine particle at a low output under 120mW. The trapped fine particle is shown in **Figure 4 (a)**, the fine particle was trapped in three dimension for the first time. And, when the focal point is set at the base plate, it can also be observed that the fine particle, shown in **Figure 4 (b)**, was levitated about 1 μ m high. However, according to the optical radiation theory, the particle should be pushed onto the base plate when the focal point is set lower than the center of silica fine particle. Although the mechanism has not been clarified by now, this experiment confirmed the fine particles in the air can be manipulated by laser beam, which makes the assembly of micro-structure by laser beam possible.

Table 2 Experimental conditions

Laser power	120mW
Q-sw repetition rate	35kHz
Objective	N.A.=0.8
Particle	SiO_2(ϕ 8.5 μ m)
Refractive index	n=1.4
Enviroment	Air
Refractive index	n=1.0



(a) (b)

Fig 4. Trapped silica particle in the air

3. Assembly of Three Dimensional Micro-Structure

3.1 Principle of assembly technique

The principle of assembly method is shown in **Figure 5**. Laser light is irradiated on a fine particle, shown in **Figure 5 (a)**, to detach the fine particle from the base plate. Then Z stage is lowered to levitate fine particle to a certain assembly height in **Figure 5 (b)**. **Figure 5 (c)** shows that the fine particle is moved horizontally. Finally, in **Figure 5 (d)**, the stage is raised to complete the assembly. According to this procedure, the assembly of three dimension micro-structure can be conducted.

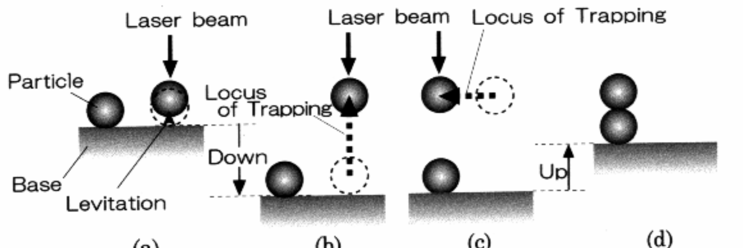


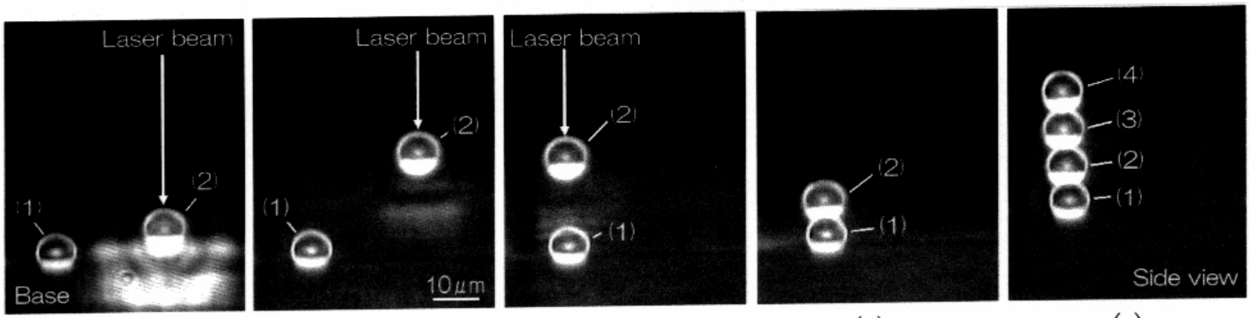
Fig.5 Procedure of micro-assembly technique by laser trapping

3.2 Experiment of assembly in vertical direction

A series of consecutive photos of experiments are shown in **Figure 6 (a) - (d)**. Silica fine particle (2) trapped in the air is shown in **Figure 6 (a)**. In **Figure 6 (b)**, the stage was lowered and particle (2) was transported to the position higher than particle (1) by vertical manipulation. **Figure 6 (c)** illustrates the transportation of particle (2) to the top of (1) by horizontal manipulation. And finally, in **Figure 6 (d)**, the stage was raised until two particles contacted. With the same procedure repeated, particle (3) and (4) were assembled in **Figure 6 (e)**. Therefore a vertical assembly was completed.

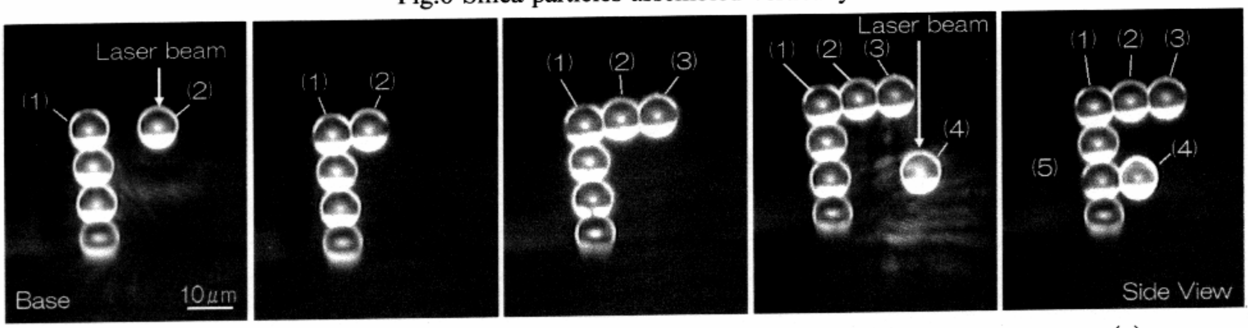
3.3 Experiment of assembly in horizontal direction

If two fine particles adsorb each other by the surface tension force, the assembly in horizontal direction may be also possible. Hereby, the assembly experiments in horizontal direction were conducted, shown in **Figure 7 (a) - (e)**. **Figure 7 (a)** and **(b)** show particle (2) was assembled to the side of vertical assembled silica fine particle (1). Similarly, silica (3) was assembled. Furthermore, in **Figure 7 (d)** and **(e)**, fine particle (4) was manipulated under (2) and (3). At this time, although part of the laser beam is disturbed by particle (2) and (3), manipulation still remains possible. Hence the more complex formation can be expected.



(a) (b) (c) (d) (e)

Fig.6 Silica particles assembled vertically



(a) (b) (c) (d) (e)

Fig.7 Silica particles assembled horizontally

3.4 Assembly of micro-structure in three dimension

After the basic assembly in vertical and horizontal directions was confirmed, the micro-structure in three dimension was conducted. Shown in **Figure 8**, the tetrahedron was assembled by 220 silica fine particles. Therefore, a three dimensional micro-structure was realized through the laser trapping technique developed in this research.

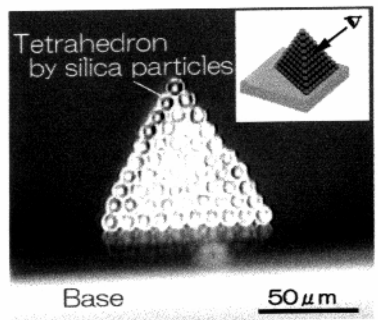


Fig.8 3-D micro-structure with a tetrahedron

4. Conclusions

The three dimensional manipulation technique of fine particles in the air and the assembly technique of micro-structure have been developed in this research. The following conclusions were obtained.

1) By using Q-switch, a fine particle can be easily trapped in the air, with an average of laser output under 120mW.

2) The fine particle was levitated 1μm high when the focal point of laser beam was set at the surface of base plate, lower than center of the particle. This phenomenon was difficult to be explained by the conventional theory.

3) The assembly of fine particles was supposed, and the assembly in vertical and horizontal direction succeeded in the experiments.

4) The assembly of three dimensional micro-structure is considered possible by using the technique developed in this paper.

-References-

1) A.Ashkin, Physical Review Letters, 24-4 (1970), 156.
2) A.Ashkin, Biophysical Journal, Vol.16 (1992), 569-582.