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Optically Vibrated Manipulation Technique of a Microsphere in a Liquid Using Plural Optical Fibers

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Abstract. In this paper, we proposed a novel optical manipulation technique of a micro-object using plural optical fibers, and verified that optically trapped micro-object could be optically vibrated without moving optical fibers. From these experimental results, we verified that our proposed optical manipulation technique was useful for the manipulation of microorganisms and biological cells.

1. Introduction

Optical trapping is a technique that is used to capture, translate, and manipulate microscopic particles, such as dielectric microspheres and cells. We have already developed a single-beam optical fiber trapping system[1][2], which was very economical and simple to operate, and experimentally investigated the optical trapping of a microsphere using a laser beam from a lensed optical fiber inserted into a sample cell at an angle[3]. A microsphere dispersed in ethanol could be trapped on the surface of a sample cell and could be manipulated forward and backward, or to the right and left synchronized to the optical fiber end.

In this paper, we propose a novel optical manipulation technique of a micro-object using plural optical fibers. From experimental investigations, we verified that optically trapped microsphere could be optically vibrated by controlling laser power emerging from optical fibers without moving optical fibers.

2. Fiber-optic trapping system

The fiber trap was formed using a temperature stabilized, 1480nm, cw diode laser (ANRITSU SD3F403D), pigtailed with single-mode fiber. The output of laser light was coupled into optical fibers, which had optical connectors at these fiber ends. Lensed optical fibers were used as trapping fibers. The fiber end had a hemispherical microlens with $\sim 5\mu\text{m}$ radius of curvature for focusing the laser beam emerging from the optical fiber end. In this case, the focused spot size at the beam waist was $\sim 3\mu\text{m}$ in ethanol solution, which was measured using an IR camera. These trapping fibers were attached to xyz manipulators and were inserted into a sample cell at an angle of 35 degrees. A microscope with a liquid-immersion microscope objective was used to observe the trapped object and the trapping behavior was recorded on a VTR with a CCD camera. This proposed optical fiber trapping method has following merits: (i) optical trapping system using optical fibers is simple and inexpensive. (ii) trapping point is easily noticeable, because the fiber end points out the focal point.

Figure 1 shows photographs of an optically trapped $10\ \mu\text{m}$ diameter polystyrene particle by the laser beam from optical fiber end. In Figure 1(a), the laser beam was emerging from the optical fiber A.

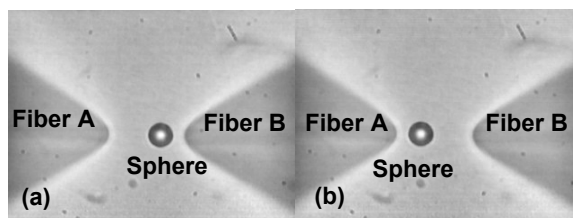


Figure 1: Optically trapped microsphere(Top view).
 (a) laser beam was emitted from optical fiber A.
 (b) laser beam was emitted from optical fiber B.

Figure 2 shows the relationship between the beam axis of laser beam emerging from optical fiber A and optically trapped particle. The particle is trapped at the point where the x directed (horizontal) optical forces are balanced. At this stable point, the total z -directed optical forces act on the sphere in the downward direction. Generally the force on a microsphere divides itself naturally into two components [2][3], which always act through the center of the sphere: one in the axial direction of the light, denoted by F_{ax} , and the other a transverse force, denoted by F_{tr} . We have already theoretically and experimentally investigated the optical force acting on a microsphere to corroborate the optical trapping by a weakly focused single laser beam from a lensed optical fiber[2][3]. These results indicate that the axial force F_{ax} always acts on the sphere in the direction of beam away from the optical fiber end, and the particle is trapped at the point where the x directed(horizontal) optical forces are balanced. Therefore a stable trap can be defined at the point where the $-x$ -directed optical force F_{trH} and $+x$ -directed optical force F_{axH} , which correspond to the projection of F_{tr} and F_{ax} along the horizontal axis, are precisely balanced, and where restoring forces act to keep the sphere at the stable point. In Figure 1(b), the laser beam was emerging from the optical fiber B. In this case, the microsphere was moved in the left direction on the sample cell and trapped where the x directed (horizontal) optical forces are balanced as shown in Figure 1(b) and 2(b). These results indicate that optical manipulation can be realized by controlling the optical power emerging from each optical fiber end without moving optical fiber ends.

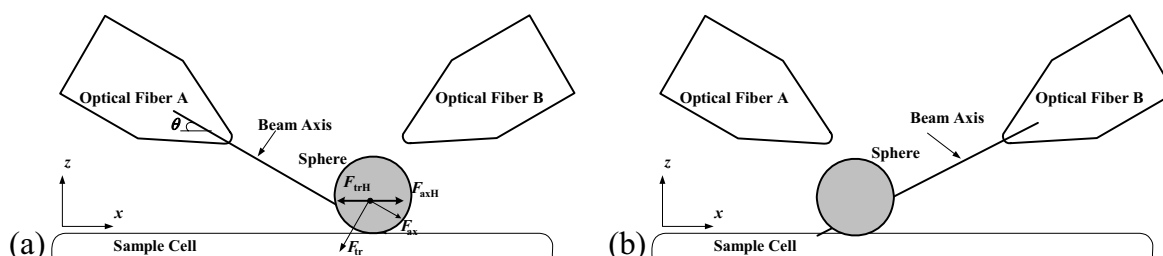


Figure 2: Relationship between the beam axis of laser beam emerging from optical fiber and optically trapped particle (Side view).

3. Optically vibrated manipulation

Next we tried optically vibrated manipulation of a trapped micro-object using plural optical fibers without moving optical fiber ends as shown in Fig. 3.

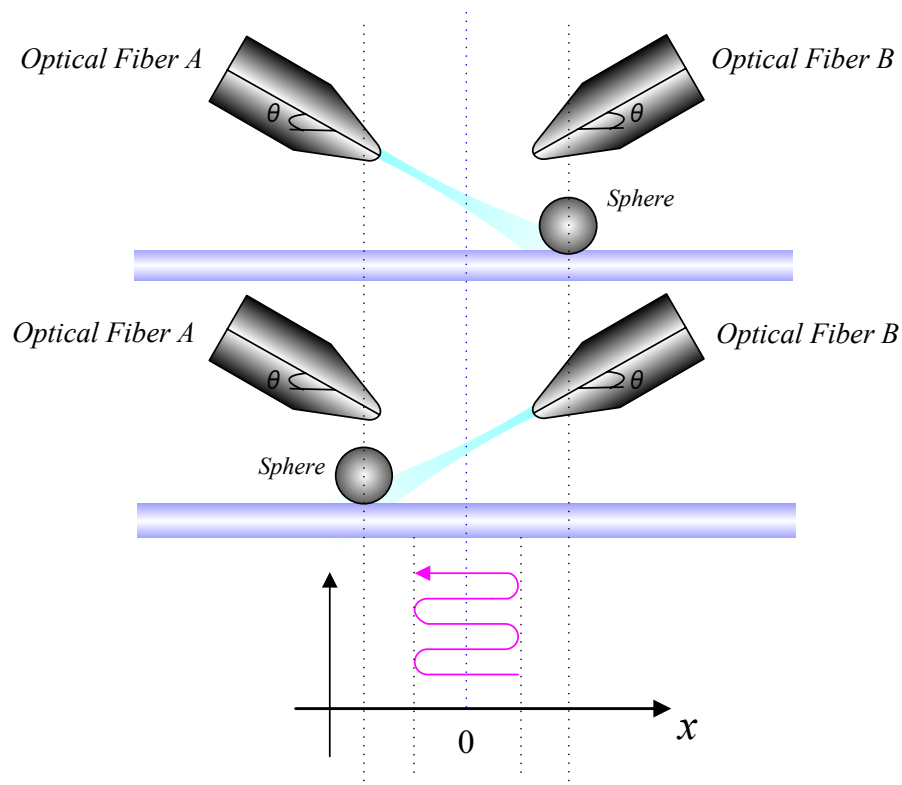


Figure 3: Optically vibrated manipulation.

Figure 4 shows the experimental setup used for experiments. The fiber trap was formed using a temperature stabilized, 1480nm, cw diode laser, pigtailed with single-mode fiber. The output of laser light was coupled into optical fibers through an optical switch as shown in Figure 4. The optical switch could be controlled by a personal computer. These optical fibers were attached to xyz manipulators and were inserted into a sample cell at an angle of 35 degrees. Experimental results were shown in Figure 5. Laser beam at 10mW was emerging from Fiber A or Fiber B. In Fig. 5, fiber end emerging laser beam was changed every ΔT using an optical switch controlled by personal computer. In Fig. 5, ΔT is 200msec, 250msec, 300msec and 450msec, respectively. From these experimental results, it was found that optically vibrated manipulation of a micro-object could be successfully demonstrated by controlling optical power emerging from optical fibers without moving optical fiber ends.

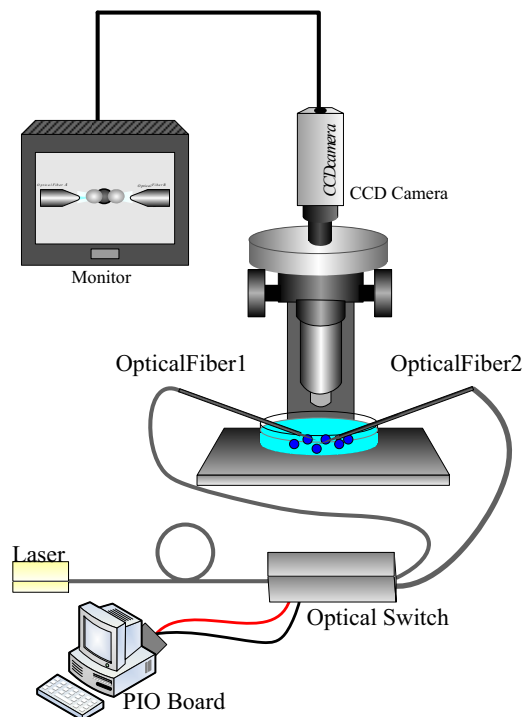


Figure 4: Experimental setup.

4. Conclusions

Optically vibrated manipulation of a micro-object was successfully demonstrated using plural optical fibers without moving optical fiber ends. From these experimental results, we verified that our proposed manipulation technique was useful for the manipulation of microorganisms and biological cells.

References

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- [2]Taguchi, K. (2001): Optical and Quantum Electronics, **33**, pp.99-106
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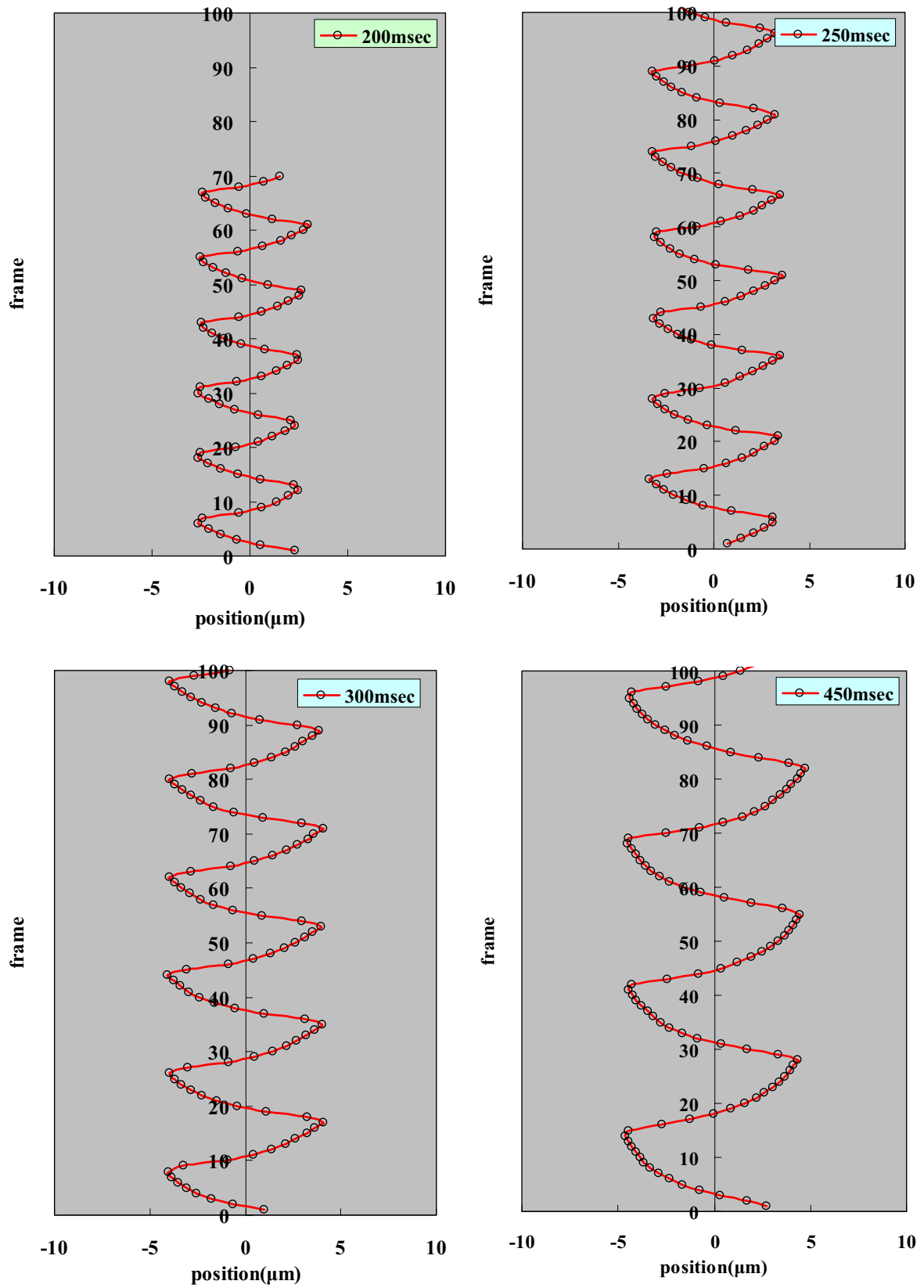


Figure 5: Experimental results.