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Laser Trapping, Spectroscopy, and Ablation of a Single Latex Particle in Water

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Simultaneous laser manipulation, spectroscopy, and ablation of a dye-doped poly(methyl methacrylate) latex particle in water was demonstrated. A minute hole with its diameter and length of ≈sub μm and 4-7 μm, respectively, was fabricated on an optically trapped latex particle (4-7 μm diameter) by laser ablation. Possible applications are briefly discussed.

A fine particle with its diameter and refractive index of 250 Å-10 μm and *n*, respectively, can be optically tweezered when laser beam is focused on the particle in the medium of *n*(medium) < *n*(particle).[1,2] This laser trapping of a fine particle has been currently studied in several research groups[1,3-6] and a theoretical explanation of the phenomenon has been also given by Ashkin et al.[1b,e] Indeed, various fine particles such as polymer latex,[1a,c,3,4] silica gels,[1c] biocells,[1d,f,3,6] and so forth[5] have been shown to be optically trapped by laser. However, the most studies were focused on the physical understanding of laser trapping itself and chemical application of the technique has been rarely explored. If a micrometer-order single particle can be manipulated, characterized, chemically modified, and fabricated simultaneously, both chemistry and physics of fine particles will be greatly advanced. As the first attempt, we explored laser trapping, spectroscopy, and ablation of a dye-doped poly(methyl methacrylate) (PMMA) latex particle in water.[7]

The laser system employed in this study is as follows. A 1064 nm laser beam from a cw Nd^{3+}:YAG laser (Spectron SL-903U) was used as a trapping laser source and was introduced into an optical microscope (Nikon, Optiphoto XF, objective lens x 100, focused into ≈1 μm). The trapping behavior was monitored by a photograph or a CCD camera-TV monitor combination. For spectroscopic measurement and laser ablation under the trapping condition, the third harmonics from a Q-switched Nd^{3+}:YAG laser (Quanta-Ray, DCR-II, fwhm=7 ns, 355 nm) was introduced into the

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microscope coaxially with the trapping laser beam and was used as an exciting light source. Fluorescence spectra were recorded by a photodiode array detector (Princeton Instruments, DSIDA) attached to the microscope through an optical fiber. Further details of the system will be reported in a forthcoming publication.[8] PMMA latex particles (diameter distribution of 5-16 μm) were gifted from Soken Kagaku Co. Ltd. Pyrene (Nacalai) and perylene (Nacalai) were purified by column chromatography, followed by repeated recrystallizations from ethanol and toluene, respectively. PMMA particles were soaked in a methanol solution of the above molecules for 1h at room temperature, filtered, and then washed with cold water. The particles were dispersed in pure water and sonicated for several seconds prior to measurements.

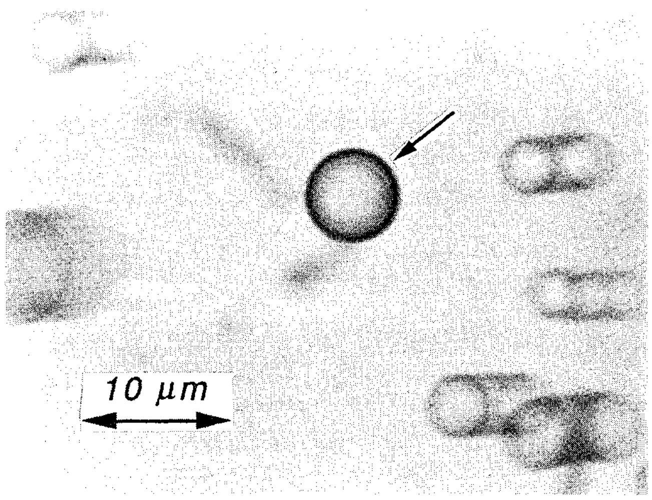

Fig. 1. Laser trapping of a pyrene-doped PMMA latex particle in water; the trapping laser power ≈900 mW.

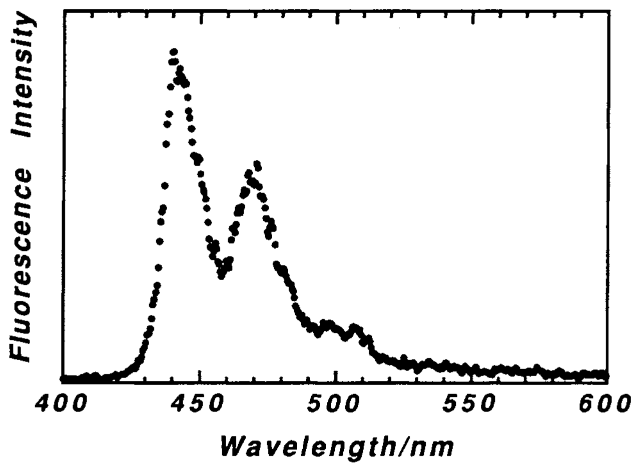

Fig. 2. Fluorescence spectrum of an optically trapped, perylene-doped PMMA latex; gate width of the detector = 0-32.5 ns, the trapping laser power ≈900 mW.

Figure 1 shows a typical example of laser trapping of a pyrene-doped PMMA latex particle in water. The trapping laser beam was illuminated perpendicularly to the plane of the photograph and the particle indicated by the allow is optically trapped by the laser beam. Since the photograph in Fig. 1 was taken with the XY stage of the microscope being moved along the X direction, untrapped particles were transferred along this direction while the trapped particle was fixed at the same position. Similarly, a single PMMA particle can be optically trapped and manipulated along the Y or Z direction as well. Laser trapping was successful for a perylene-doped latex particle as well as for a latex without dye-doping.

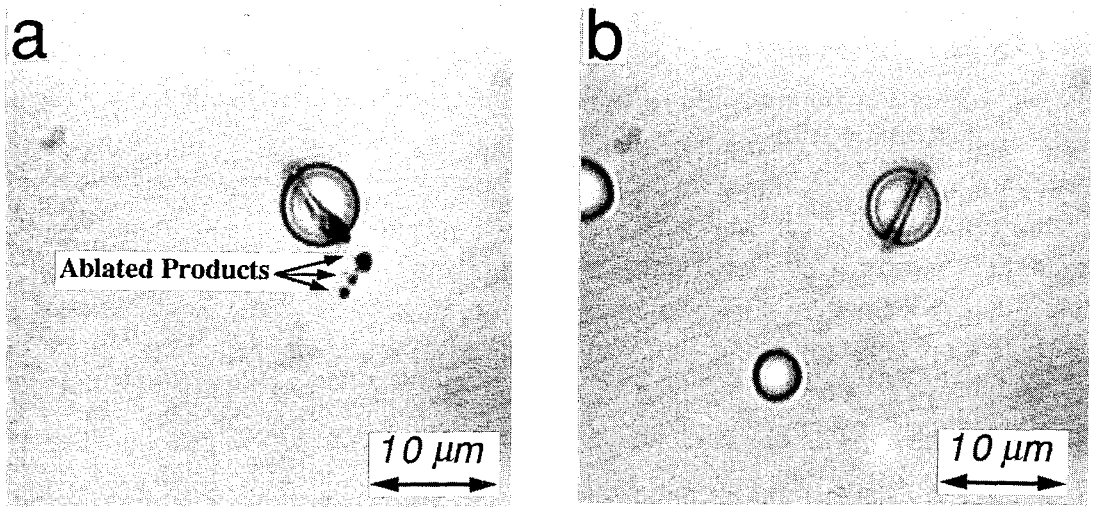

Fig. 3. Laser ablation of an opticaly trapped, pyrene-doped PMMA latex particle in water. The trapping and the excitation laser powers; a) ≈1 W and 34 J/cm^2, respectively. b) ≈1 W and 23 J/cm^2, respectively.

Spectroscopic characteristics of an optically trapped particle were studied by the present method. Namely, fluorescence spectrum from a trapped particle was obtained by exciting the particle by the pulsed laser. For a perylene-doped particle, the vibrational structure of the fluorescence from perylene was well resolved (Fig. 2) and the fluorescence dynamics of the particle can be easily investigated. We suppose that the present technique could be applied to discriminate a single particle from various dye-doped particles. Also, we recently succeeded to measure picosecond fluorescence dynamics of an optically trapped particle in water.[9] Picosecond time-resolved spectroscopy combined with the laser trapping technique will be promising to elucidate photochemical/ photophysical processes occurring in various fine particles.

When the intense 355 nm laser pulse is irradiated on a trapped, dye-doped latex particle, laser ablation of the particle is observed even in water. Figure 3a clearly demonstrates that an optically trapped PMMA particle is ablated by one shot laser pulse (355 nm) and the ablated products are ejected into the bulk water phase. Depending on the focal point in the solution and intensity of the pulse laser, a small hole with its diameter and length of < 1 µm and 4-7 µm, respectively, can be fabricated on a trapped particle as shown in Fig. 3b. It is worth noting that, when an untrapped latex particle was irradiated by the pulsed laser, we could not confirm laser ablation since the untrapped particle disappeared from the ocular field. Laser trapping is necessary for precise microfabrication of a particle dispersed in solution.

The present study shows that laser trapping is indispensable for manipulation and/or fabrication of a single fine particle in Brownian motion. Until now, the laser trapping technique has received attention in the field of biophysics and, living materials such as bacteria, cells, and so forth are nice target systems. Recently, Kasuya and Tsukakoshi reported microsurgery in living cells and micro-injection of foreign substances into cells based on laser-microscope technique.[10] Now, our approach of laser trapping-spectroscopy-ablation has made it possible to obtain molecular as well as electronic information of the trapped particle and to induce ablation as well as photochemical reaction on it. Namely, microfabrication/micromodification of various artificial fine particles such as polymer beads/latex, microcapsules, organic/inorganic catalysts, and so forth is possible, which is in progress in our research group and will be reported in near future.

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