Opto-thermal trapping by directly heating the water solvent with a 2 μm Tm-doped fiber laser

Toyota Technological Institute, °Roukuya Mamuti, Takao Fuji, and Tetsuhiro Kudo

E-mail: roukuya@toyota-ti.ac.jp

A temperature gradient in the water solvent induced by a focused laser beam can be used for trapping and manipulating tiny particles. It is known as an optothermal trapping and/or optothermal tweezers. During the past decade, a number of works using plasmonic-based optothermal trapping have been reported [1]. Typically, visible or near infrared lasers excite the surface plasmon mode of metallic nanofilms and nanostructures, which heat up the water solvent indirectly through intermediate metallic materials. In early studies, 1400 to 1500 nm lasers were used to directly heat the water solvent since the water has an absorption peak around those wavelengths [2]. Even stronger absorption peaks appear at wavelengths of 2 μm and 3 μm, respectively.

In this study, we use a 1956 nm Tm-doped fiber laser that is directly and strongly absorbed in water solvent without the intermediate materials. Collimated laser is reflected up by a dichroic mirror and focused at the bottom-glass/solution interface as illustrated in the inset of Fig. 1.

To show a temporal evolution of the assembling, we conduct the optothermal trapping of 1 μm polystyrene particles (see Fig. 2). The 2 μm laser of 10 mW is directly absorbed into water solvent and creates the temperature gradient around the focus. Under the irradiation, the particles are trapped at the laser focus, forming a monolayer of hexagonal close-packed structure, and its assembly size grows gradually over time (see Fig. 2(b-d)). When the laser is turned off, the assembly disperses gradually to the solution (see Fig. 2(g-j)). Interestingly, by replacing water solvent with heavy water (D_2O) solvent, no particles are trapped at the focus (see Fig. 2(i-l)) as the absorbance of D_2O at 2 μm wavelength is less than H_2O, indicating the temperature elevation is indeed the origin of the accumulation of the particle at the focus [3].

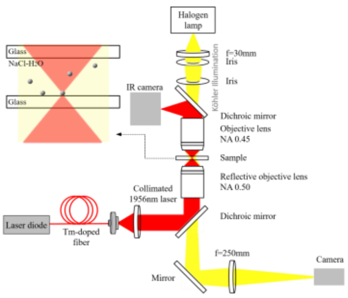

Fig.1 (a) Setup for opto-thermophoretic trapping. Inset shows an illustration of a focused laser beam and sample chamber configuration.

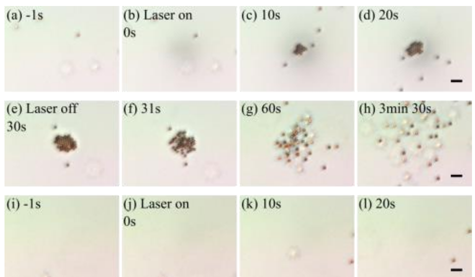

Fig.2 The transmission images of 1 μm polystyrene particles trapped by 2 μm Tm-doped fiber laser. (a) Before turning on the laser. (b-d) Temporal changes after turning on the laser. (e-h) The assembly releasing process after turning off the laser. (i-l) Temporal changes when water solvent is replaced with D_2O. The black bar length is 5 μm.

References

[1] L. Lin, M. Wang, X. Peng, E. N. Lissek, Z. Mao, L. Scarabelli, E. Adkins, S. Coskun, H. E. Unalan, B. A. Korgel, L. M. Liz-Marzán, E.-L. Florin and Y. Zheng, Nat. Photon. **12**, 195-201 (2018).

[2] K. Setoura, T. Tsuji, S. Ito, S. Kawano, and H. Miyasaka, Nanoscale **11**(44), 21093-21102 (2019).

[3] R. Mamuti, T. Fuji, and T. Kudo, Opt. Express 29, 38314-38323 (2021).