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Femtosecond Laser-Enhanced Immobilization of a Single Submicron-Sized Dielectric Particle

Natl. Chiao Tung Univ., Taiwan; ○Tsung-Han Liu, Anwar Usman, Wei-Yi Chiang, Hiroshi Masuhara

E-mail: murasaki.imo98g@nctu.edu.tw

A conventional approach in laser trapping is to utilize a highly focused continuous wave (cw) laser beam as a trapping light source to generate pN-scale gradient force. Recently, substituting cw- with pulse-mode lasers has been demonstrated to enhance the trapping efficiency, particularly when the target particles are within Rayleigh approximation.[1,2,3] Here we report that substituting cw- with fs pulse-mode lasers leads to longer immobilization time of a single particle at the focal spot, even for 500-nm-sized dielectric particle in Mie-scattering regime.

Experimentally, we employed a laser beam from Ti:Sapphire (800 nm), which can be operated in fs pulse (90 fs; 80 MHz)- or cw-mode. The beam was focused by an objective lens (60×; NA 0.90) into a sample cell containing colloidal solution of 500 nm polystyrene beads suspended in water. Optical trapping of a single particle was monitored by both scattering light (detected by CCD camera) and transmittance of the trapping beam (detected by avalanche photodiode).

Fig. 1 shows the transmission change as a function of irradiation time of fs pulses or cw laser and immobilization of a single particle at the focal spot, which is simultaneously confirmed from the scattering light imaging. The stable immobilization can be achieved by laser power of about 2.5 to 10 mW. At higher laser power, however, ejection is led due to the scattering force characteristic of fs pulses. Interestingly, with essentially the same optical conditions, immobilization time is much longer for fs pulses as compared with cw laser. From the image size of the immobilized particle, the trapping position in both laser modes is estimated approximately similar; i.e. about 1 μm above the focal plane, inside the trapping volume, along the beam propagation. We consider that the stable immobilization at low laser power is due to impulsive peak of fs laser pulses that can generate extremely strong transient attractive forces, and the highly repetitive laser pulses allows an optical trap of the particle without its severe diffusion out from the trap site during the interval time between pulses. These findings will be discussed in detail along with the possibility to trap single macromolecules by fs laser pulses.

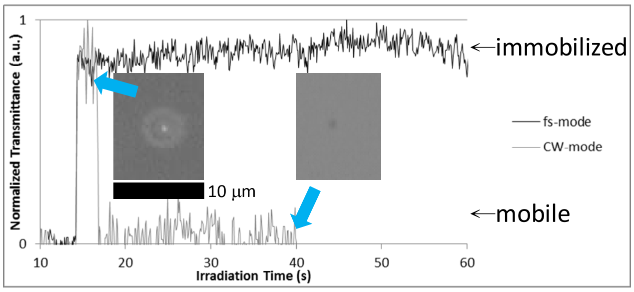

Fig. 1. The transmission change as a function of irradiation time of focused fs pulses (black line) and cw laser (gray line) at 2.5 mW. The images correspond to an immobilized single 500 nm polystyrene bead (left) and a mobile one (right) at the focal spot.

References:

[1] L. Pan, A. Ishikawa, N. Tamai, *Phys. Rev. B* **2007**, *75*, 161305.

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[3] A. Usman, W.-Y. Chiang, H. Masuhara, *Science Progress* **2013**, *96*, 1-18.