Stationary bubble formation and optofluidics induced by CW laser heating of a single gold nanoparticle.

(Osaka Univ.) SETOURA, Kenji; ITO, Syoji; MIYASAKA, Hiroshi

[Introduction] Gold nanoparticles (Au NPs) exhibit strong light absorption due to the localized surface plasmon resonance (LSPR), and efficiently convert light energy into heat. Heat transfer from Au NPs to surrounding medium induces the local temperature increase, resulting in nanobubbles generation owing to the explosive evaporation of medium [1]. In particular, stationary bubbles can be produced by illuminating CW laser for individual Au NPs [2]. These stationary bubbles in microscopic region drive fluid convection of medium and suggest the potential application to the manipulation of colloidal particles and molecules. In the present work, we have investigated the thermo-physical properties of the stationary bubbles and fluid convection of surrounding water by integrating experimental results with those by the theoretical calculation. From these results, it was revealed that the surface tension of stationary bubbles is a key factor to control the fluid convection in microscopic region.

[Experimental] Aqueous solution of Au NPs with nominal diameters of 150 nm was spin-coated onto a 24 × 32 × 0.17 mm glass coverslip. Au NPs on a glass coverslip were immersed in distilled water in a 90μL chamber consisting of two coverslips sandwiched with a 0.3 mm thick silicone rubber spacer (Fig. 1a). Laser illumination for individual Au NPs were carried out through microscope objective (40×, NA = 0.75) on an inverted optical microscope, using a focused 532 nm CW laser beam. To visualize the fluid convection by wide-field fluorescence imaging of excitation wavelength at 488 nm, small amounts of 40-nm-diameter fluorescent polystyrene beads (FL-beads) were added into distilled water.

[Results and Discussion] Figure 1b shows the relation between the diameter of stationary bubbles monitored by transmission imaging and the laser peak power density. Formation of stationary bubble was observed above the threshold peak power density of 10 mW μm⁻². The diameter of bubbles increases with increasing peak power density above the threshold.

Figure 1. (a) Schematic illustration of the formation of stationary bubble and fluid convection. (b) Diameter of stationary bubbles as a function of laser peak power density.
To evaluate the threshold of bubble formation, we estimated the temperature of a single Au NP under CW laser illumination by employing numerical calculation with a heat conduction model developed in our previous work [2]. Temperature of a Au NP and water adjacent NP surface was estimated 650 K, which is almost the same with the critical temperature of water ($T_c$: 647K). This result suggests that the water layer adjacent to the Au NP can induce the formation of the bubble owing to the explosive evaporation or spinodal decomposition occurring at the temperature > $T_c$. Note that the diameter of bubble is quite stable at least 1 or 2 minutes under CW laser illumination.

Fluid convection around stationary bubbles was observed by using a wide-field fluorescence imaging as shown in Fig. 2a, showing that FL-beads moving toward the stationary bubble are accumulated at water / vapor interface over time under the laser illumination. After the CW laser at 532 nm was turned off following the 30-seconds illumination, the stationary bubble slowly shrunk and disappeared within a several second. To evaluate the convective motion and accumulation of FL-beads, numerical calculation was employed on the basis of heat conduction and Navier-Stokes equation (Fig. 2b).

Generally, fluid convection can be divided into two cases; natural convection and Marangoni convection. The driving force of natural convection is the density differences in the fluid occurring due to the temperature gradients. On the other hand, surface tension at liquid / fluid interface plays a major role for Marangoni convection. At the conference site, we will discuss the mechanism and the control method of two kinds of convections driven by CW laser heating of Au NPs by showing detailed experimental and theoretical results.

![Figure 2](image_url)

Figure 2. (a) Snapshots of convective motion and accumulation of FL-beads to water / vapor interface. Scale bar: 5 μm (b) Computational 2-D temperature distribution and fluid motion.
