Opto-thermal Induced Flow Enables Faster Trapping in Nanoaperture Tweezers

Abhay Kotnala, Pavana Siddhartha Kollipara and Yuebing Zheng*
Walker Department of Mechanical Engineering, Material Science and Engineering Program and Texas Material Institute, The University of Texas at Austin, Texas 78712, USA
**Corresponding author: zheng@austin.utexas.edu*

Abstract: Opto-thermal induced flow was integrated with nanoaperture tweezers to overcome the diffusion-limited trapping process, which resulted in more than an order-of-magnitude reduction in particle trapping time. © 2020 The Author(s)

1. Introduction

Nanoaperture tweezers have shown promising applications in single particle manipulation, sensing and spectroscopy[1,2]. However, the trapping or sensing process is mostly diffusion-limited as the particle needs to travel to the proximity of the nanoaperture before it can be trapped by the short-range plasmonic forces at the nanoaperture. This results in long wait-times to trap a particle, which can increase substantially (up to hours) for low concentrated samples. In this work, we integrate opto-thermally generated Rayleigh-Bénard and bubble-induced Marangoni convection flows with nanoaperture tweezers to quickly deliver particles from large spatial distances to the nanoaperture trap and overcome the diffusion-limited trapping. We refer to these trapping systems as convection- and bubble-assisted traps respectively, and they reduce the particle trapping time by 1-2 orders of magnitude.

2. Bubble- and convection-assisted traps

Fig. 1(a) shows the schematic of the experimental set-up of a bubble-assisted trap. Two lasers, 532 nm (for bubble generation) and 1020 nm (for trapping) were focused on a gold nano-islands (AuNIs)-encapsulated nanoaperture (inset). AuNIs are needed for efficient bubble generation. The opto-thermally generated bubble induces Marangoni convection resulting in a rapid flow and capture of particles at the bubble-water interface, which are then trapped at the nanoaperture after the bubble collapses. The particles were delivered to the nanoaperture from distances as large as 200 µm with velocities ranging from 10 µm/s to 100 mm/s (Fig.1b) and thus reduce the particle travel time to the nanoaperture (Fig.1b).

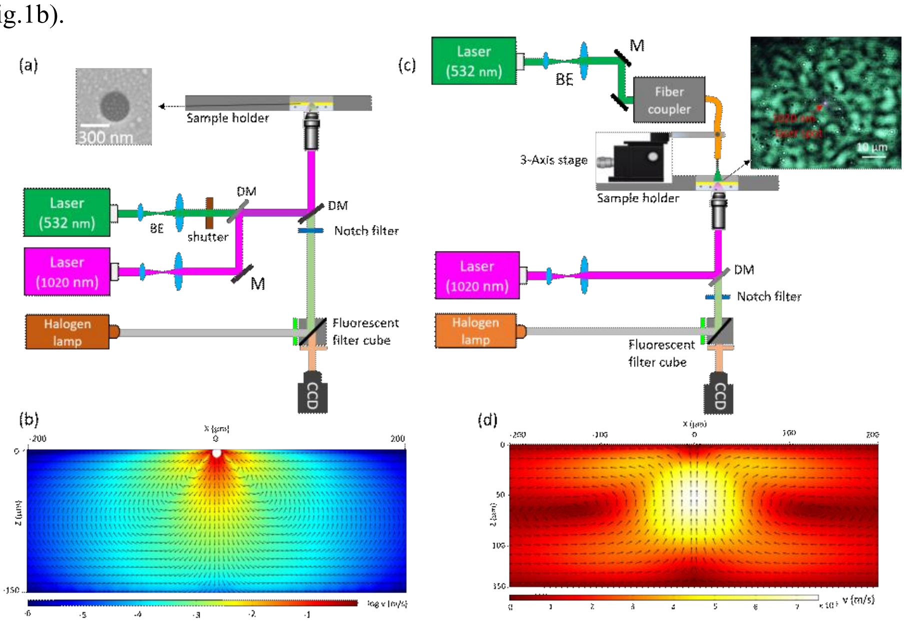

Figure 1: (a) Schematic of the experimental set-up of a bubble-assisted trap. (b) Simulated flow velocity distribution in the solution due to Marangoni convection in a bubble-assisted trap. (c) Schematic of the experimental set-up of a convection-assisted trap.(d) Simulated flow velocity distribution in the solution due to Rayleigh-Bérnard convection in a convection-assisted trap.

A convection-assisted trap exploits strong Rayleigh-Bénard convection flow generated by illuminating a large area (D > 50 µm) of Au film around the nanoaperture using a multimode optical fiber as shown in Fig.1c., to rapidly and continuously transport particles to the vicinity of a nanoaperture. Some trajectories in the complex convection flow field can transport particles from distances larger than 100 µm towards the nanoaperture with a velocity of 20 µm/s as shown in Fig.1d, and thereby reduce the particle trapping time.

3. Results and Discussions

3.2.1 Trapping of 200 nm nanoparticles using a bubble- and convection-assisted trap

Figure 2(a-e) and 3(a-e) shows the trapping of a single 200 nm fluorescent polystyrene particle (marked by arrows) using a bubble-and convection-assisted trap, respectively.

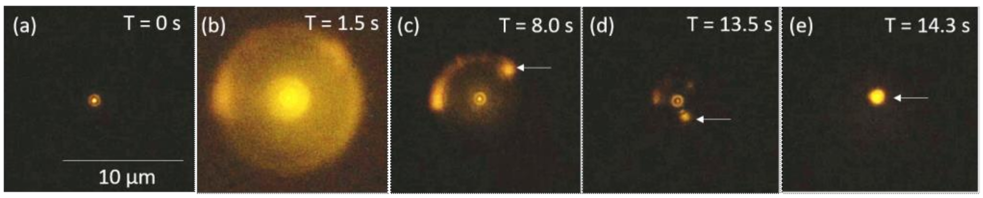

Figure 2 (a-e) Time-lapsed images showing trapping of 200 nm fluorescent polystyrene particle in a bubble-assisted trap

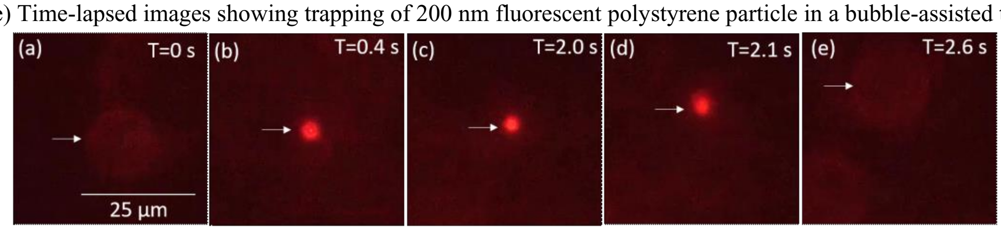

Figure 3 (a-e) Time-lapsed images showing trapping of 200 nm fluorescent polystyrene particle in a convection-assisted trap.

3.2.2 Quantitation of average particle trapping time for a bubble- and convection-assisted trap

The particle trapping time for a bubble-assisted trap was measured as the time interval between the generation of the bubble and trapping of a particle at the nanoaperture, while for the convection-assisted trap it was measured as the time-interval between multiple trapping events. The particle trapping time was reduced by 1-2 order of magnitude by bubble- and convection-assisted trap compared to a diffusion-limited trap as shown in Fig.3.

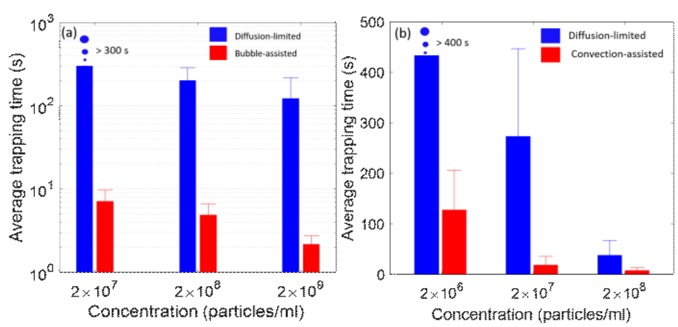

Figure 3: Comparison of average particle trapping time of (a) Bubble-assisted and (b) convection assisted trap with diffusion-limited trap at different particle concentrations.

4. References

1. Koya, A. N. *et al.* Novel Plasmonic Nanocavities for Optical Trapping-Assisted Biosensing Applications. *Adv. Opt. Mater.* **8**, 1901481 (2020).

2. Al Balushi, A. A. *et al.* Label-free free-solution nanoaperture optical tweezers for single molecule protein studies. *Analyst* **140**, 4760–4778 (2015).