Trap Stiffness in Negative Optoelectronic Tweezers (OET)

Steven L. Neale and Ming C. Wu
Berkeley Sensor and Actuator Center (BSAC) and Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, CA 94720
sln2@eecs.berkeley.edu

Optoelectronic Tweezers (OET) allow the control of micron-sized particles suspended in a liquid by controlling the dielectrophoretic force with the selective illumination of a photoconductor [1]. High liquid conductivities give a negative force (away from illuminated areas) so that particles are trapped by illuminating a ring around them. This paper explores the force profile of these traps and shows that high stiffness traps can be created (8×10^{-7} Nm^{-1}), with a linear profile, at low optical powers (8.29µW).

OCIS codes: (350.4855) Optical tweezers or optical manipulation

1. Introduction

Optoelectronic tweezers (OET) is a new optical manipulation technique that allows massively parallel traps [1]. Using optically-induced dielectrophoresis (DEP) on a photoconductive electrode, OET offers orders of magnitude reduction in optical power requirement. The OET trap can be either positive (attraction) or negative (repulsion), depending on the conductivity of the liquid media and the relative dielectric constants of the particle and the media. Previously, we have experimentally characterized the stiffness of positive OET traps [3]. In this paper, we report the first characterization of the stiffness and force profile of negative OET traps.

The OET chamber consists of an analyte sandwiched between two indium-tin-oxide (ITO)-coated glass slides, one of which is coated in a photoconductor, here amorphous silicon (a-Si). An A.C. voltage source is placed across the chamber. We use a digital-micromirror-device (DMD) projector to generate the trapping patterns. For negative OET, we use a ring pattern to trap the particle (see Figure 1).

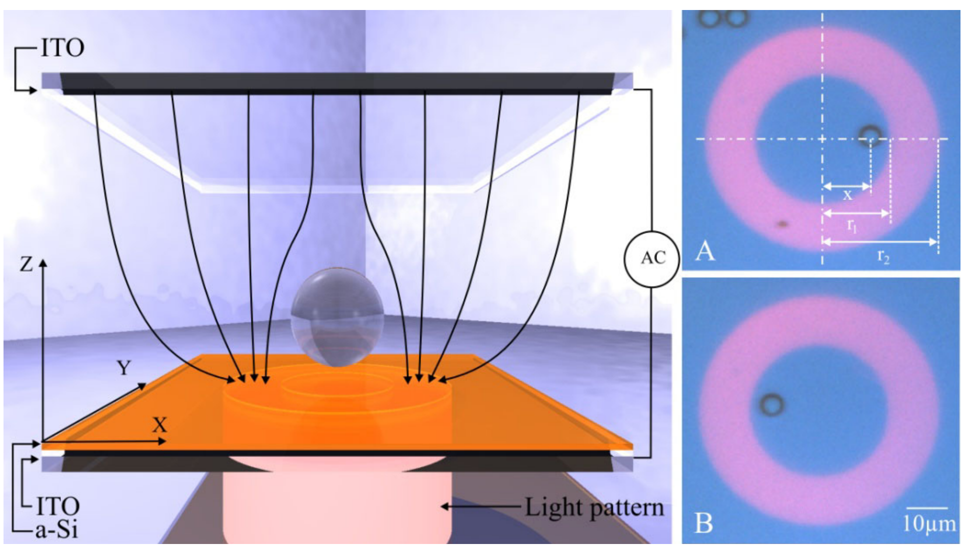

Figure 1. An OET chamber consists of a liquid layer containing the beads sandwiched between two ITO-covered glass plates, one of which has a-Si covering it. When the stage is moved to the right, or positive x direction (A), and then left, or negative x direction (B), the particle is pushed in that direction. By decreasing the radius of the trap the distance the particle moves decreases, increasing the trap stiffness.

2. Theory and experiment

The force due to DEP is given by [2], $F_{DEP} = 2\pi r^3 \varepsilon_m Re[K(\omega)]\nabla E^2$, where Re[K(ω)] is the real part of the Clausius-Mossotti (CM) factor, a frequency dependent factor between -0.5 and 1 that depends on the relative complex permittivities of the particle and the medium it is in. These in turn depend on their conductivities. When the CM factor is negative, the force is repulsive. Thus to trap a particle we illuminate a ring around the particle. The

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profile of this trap is therefore more complicated than the previously considered case of a positive OET trap [3]. To study the force profile of the trap, experiments were performed where the stage is moved with respect to the camera and the illuminating pattern. This puts a drag force on the particle that can be calculated for a known size particle a known distance from the surface [3]. Here the particles are assumed to be in contact with the surface, which is true for trapped particles. The particle will move within the trap until the drag force is equal to the DEP force, so by measuring the particles position within the trap as the stage is moved at different velocities, the force at different positions can be measured (see Figure 2). The experiments were performed with 5µm diameter silica beads in 1.5mS/m conductivity liquid with a voltage of 3.5V at a frequency of 100kHz. These conditions gave a maximum trapping velocity of 25µm/s.

To compare the experimental results with theory, numerical simulations were performed using COMSOL Multiphysics package. Here, Maxwell's equations are numerically solved in the quasi-static approximation. These simulations give the gradient of the square of the electric field which can then be used to find the DEP force with the DEP equation shown earlier. The CM factor was calculated to be -0.25.

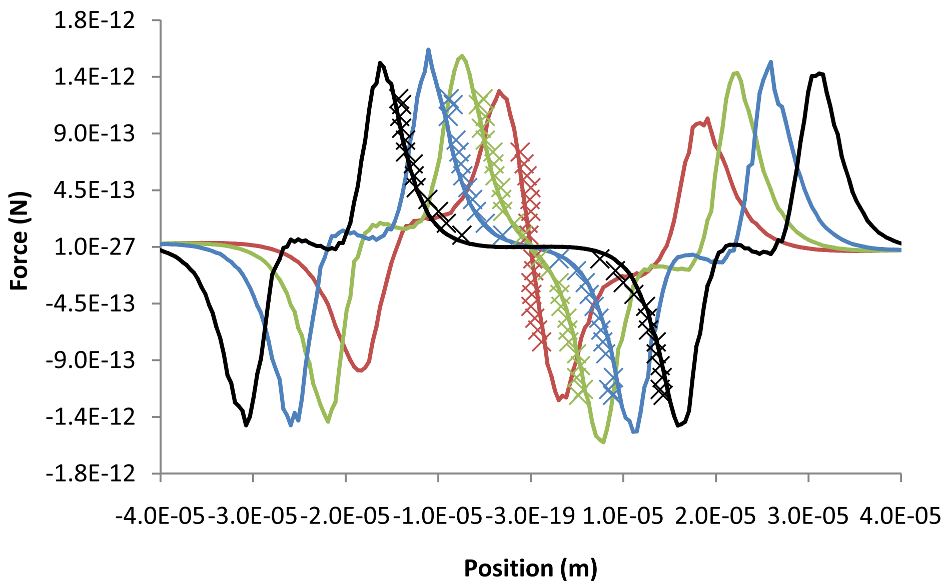

Figure 2. The experimental results (crosses) are compared with simulated results (solid lines) for the force profile of the ring traps of different radius. The width of the illuminated line was kept constant (13 µm) and the radius r_1 was varied: r_1 = 3.9 (red), 8.2 (green) 11.9 (blue), 17.2µm (black). The error in the measured positions is roughly equal to one pixel of the analysed image or 0.2µm.

3. Results and Conclusion

Figure 2 shows that with a large radius the trap does not have a straight line profile with a single stiffness value, but as the radius reduces, it approaches an ideal trap. When r_1 = 3.9µm, it does resemble a straight line with a stiffness of $8x10^{-7}$ Nm^{-1}. This stiffness is about five times larger than the positive OET traps and about 2000 times larger than conventional optical tweezers using the same power [3]. The enhancement over positive OET is mainly due to the higher photoconductivity of the a-Si used in this experiment. The fact that we can produce a trap with a high stiffness that is constant at the centre of the trap with negative OET is important as this gives precise control over the position of the particle. Negative OET is an important regime as cells in a high conductivity liquid, such as cell culture medium, will experience a negative force. The force is limited by the particle eventually lifting from the surface and moving over the trap rather than through it [4], thus future work will include varying the colloid density to study this effect.

[1] P.Y. Chiou, A.T. Ohta and M.C. Wu, "Massively parallel Manipulation of single cells and microparticles using optical images", Nature 436, 370-372 (2005).
[2] M.P. Hughes, "Nanoelectromechanics in Engineering and Biology", CRC (2003).
[3] S.L. Neale, M. Mazilu, J.I.B. Wilson, K. Dholakia, T.F. Krauss, "The resolution of optical traps created by light induced dielectrophoresis (LIDEP), OPEX 15 (20): 12619-12626 (2007).
[4] A.T. Otha, P.Y. Chiou, T.H. Han, J.C. Liao, U. Bhardwaj, E.R.B McCabe, F. Yu, M.C. Wu, "Dynamic Cell and Microparticle Control via Optoelectronic Tweezers" JMEMS, Vol. 16, No.3 491-499 (2007).