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2017

Zhao, H., Zhang, Y., Chin, L. K., Yap, P. H., Wang, K., Ser, W., & Liu, A. Q. (2017). Nanoparticle sorting in silicon waveguide arrays. Proceedings of SPIE - Optical Trapping and Optical Micromanipulation XIV, 10347, 103472L-. doi:10.1117/12.2273251

<https://hdl.handle.net/10356/106406>

<https://doi.org/10.1117/12.2273251>

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Nanoparticle sorting in silicon waveguide arrays

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ABSTRACT

This paper presents the optical fractionation of nanoparticles in silicon waveguide arrays. The optical lattice is generated by evanescent coupling in silicon waveguide arrays. The hotspot size is tunable by changing the refractive index of surrounding liquids. In the experiment, 0.2- μm and 0.5- μm particles are separated with a recovery rate of 95.76%. This near-field approach is a promising candidate for manipulating nanoscale biomolecules and is anticipated to benefit the biomedical applications such as exosome purification, DNA optical mapping, cell-cell interaction, etc.

Keywords: near-field, optical fractionation, waveguide array

1. INTRODUCTION

Optical manipulation grows enormously benefitting from the technical advance in nanofabrication [1], single molecule detection [2], optofluidics [3], etc. It utilizes the light-matter interaction in an optical field to achieve functionalities such trapping, sorting and patterning. The manipulation of nanoscale objects is of great interest in physical and life science because it allows the precise control of biological objects such as bacteria, viruses, DNA, etc. Various near-field techniques have been developed to trap an individual nanoparticle [4, 5], but the parallel manipulation and sorting of nanoparticles is still a challenge. Conventionally, sophisticated optical fields are engineered by spatial light modulator to separate microparticles [6], but due to the large spot size limited by diffraction barrier, the approach is inefficient to deal with nanoparticles.

This paper presents the optical fractionation of nanoparticles in silicon waveguide arrays. The optical lattice is generated by evanescent coupling in silicon waveguide arrays. This method is anticipated to benefit the broad biomedical applications such as exosome purification, DNA optical mapping, cell-cell interaction, etc.

2. PRINCIPLE AND FORCE ANALYSIS

Figure 1 illustrates the separation of different sized particles in the optofluidic system. The optical lattice is formed by the back and forth coupling in each pair of the waveguide-pair array. Each localized optical field is called a hotspot. The different sized particles are hydrodynamically focused near to the left sidewall of the microchannel. When the particles flow through the optical lattice, the particles will have distinct trajectories: the large particle (red) has the most significant lateral displacement, the medium particle (blue) have the modest displacement, and the small particle (green) have the negligible displacement. They can be collected by multiple outlets in the downstream.

Since the particle radius is smaller than 1/6 of the wavelength, the optical force is calculated using Rayleigh approximation [16]. The light intensity is obtained from FDTD simulation result. The particle is assumed to be 50 nm above the surface, the guided power in a waveguide-pair is 3 mW, and the particle velocity is 10 $\mu\text{m/s}$. Figure 2 shows the x -component and y -component of the resultant force on 200-nm and 500-nm particles. The result shows that in the x -direction, the optical scattering force is dominant for the 500-nm particle, while the gradient force dominant for the 200-nm particle. The resultant force on a 500-nm particle is ~60 times larger than that on the 200-nm particle. On the other hand, in the y -direction, the resultant force can be zero in the dashed-box, i.e. the particle is trapped in the y -direction. The trapping region (dashed-box) of the 500-nm particle is larger than that of the 200-nm particle as shown in Figure 2(c) and

(d). When a particle flows outside the dashed-box, it moves along the flow in the y -direction, and is deflected slightly in the x -direction. However, when a particle flows into the dashed-box, it stops moving in the y -direction, then deflected significantly along the waveguide, and eventually leaves the optical field at the edge of the trapping region.

Figure 1. Schematic illustration of particle separation in the optofluidic system.

Figure 2. Calculated x -component of the resultant force distribution for (a) 200-nm and (b) 500-nm particle. Calculated y -component of the resultant force distribution for (c) 200-nm and (d) 500-nm particle. (Dashed box: the trapping region)

3. RESULTS AND DISCUSSIONS

The trajectories of 200-nm and 500-nm polystyrene particles are studied experimentally. The particles are hydrodynamically focused near to the left sidewall. The laser power coupled into the device is ~ 100 mW and the guided power in each waveguide-pair is ~ 3 mW. Figure 3 shows that the particles are separated after flowing through the optical field: the lateral displacement of the 200-nm particle is -1.415 μm , while that of the 500-nm particle is 79.18 μm .

Figure 3. Trajectories of 200-nm and 500-nm particles.

Figure 4. Optical image of accumulated *Shigella* bacteria on the surface.

The particle displacement in the y -direction as a function of time is also analyzed. The result shows that the 200-nm particle (green line) has nearly constant velocity before and after entering the optical field, i.e. the optical force have negligible influence on the 200-nm particle. In comparison, the 500-nm particle (orange line) slows down considerably at $t = 2.5$ s after entering the optical field. The particle is trapped and moves discontinuously in the y -direction. The 200-nm particle moves slightly slower than the 500-nm particle before entering the optical field because it is nearer to the sidewall. The particle displacement in the y -direction as a function of time is analyzed. The result indicates that the motion of the 200-nm particle is dominated by Brownian fluctuation in the x -direction. The optical force is too small to deflect the 200-nm particle. Whereas the 500-nm particle moves gradually in the x -direction. The overall velocity is 2.45 $\mu\text{m/s}$, and the peak velocity, which occurs in the trapping regions, is 4.61 $\mu\text{m/s}$.

The particle distribution of massive particles before and after the optical field is analyzed statistically. Figure 4(a) shows the probability density at different lateral positions before entering the optical field. It indicates that 92.85% of 200-nm, 100% of 500-nm particles locate at the left side of the microchannel (0 - 50 μm). The particle distribution follows a Gaussian profile with the center position of 26.7 μm and 21.4 μm for 200-nm, and 500-nm, respectively. When the particles flow through the optical field, the particle distribution changes dramatically: 91.63% of the 200-nm particles stay in the left half side of the microchannel (0 - 50 μm), while 95.76% of the 500-nm particles move to the right side (91 - 100 μm). The particle distribution still follows a Gaussian profile, but the center position changes to 24.3 μm and 96.6 μm . The result demonstrates that 500-nm particles are separated out from the particle mixture with high accuracy.

4. CONCLUSIONS

In conclusion, this paper presents the optical fractionation of nanoparticles in an optical lattice. The optical lattice is generated by evanescent coupling in nano-waveguide arrays. The hotspot size is tunable from 9.8 to 5.3 μm by changing the surrounding refractive index from 1.332 to 1.430. In the experiment, 0.2- μm and 0.5- μm particles are separated with a recovery rate of 95.76%. This near-field approach is a promising candidate for the sorting of nanometric molecules and is anticipated to benefit applications such as diagnostics, chemical and biological analyses, chemical processing, etc.

ACKNOWLEDGMENTS

This work is supported by the National Research Foundation, Singapore, under the Competitive Research Program (Program No.: NRF2014NRF-CRP001-002).

REFERENCES

- [1] M. Daly, M. Sergides, S. Nic Chormaic, Optical trapping and manipulation of micrometer and submicrometer particles, *Laser & Photonics Reviews*, 9(2015) 309-329.
- [2] Y. Pang, H. Song, J.H. Kim, X. Hou, W. Cheng, Optical trapping of individual human immunodeficiency viruses in culture fluid reveals heterogeneity with single-molecule resolution, *Nat Nano*, 9(2014) 624-630.
- [3] H.T. Zhao, Y. Yang, L.K. Chin, H.F. Chen, W.M. Zhu, J.B. Zhang, P.H. Yap, B. Liedberg, K. Wang, G. Wang, W. Ser, A.Q. Liu, Optofluidic lens with low spherical and low field curvature aberrations, *Lab on a Chip*, 16(2016) 1617-1624.
- [4] M. Soltani, J. Lin, R.A. Forties, J.T. Inman, S.N. Saraf, R.M. Fulbright, M. Lipson, M.D. Wang, Nanophotonic trapping for precise manipulation of biomolecular arrays, *Nat Nano*, 9(2014) 448-452.
- [5] S. Mandal, X. Serey, D. Erickson, Nanomanipulation using silicon photonic crystal resonators, *Nano Lett*, 10(2010) 99-104.
- [6] M.P. MacDonald, G.C. Spalding, K. Dholakia, Microfluidic sorting in an optical lattice, *Nature*, 426(2003) 421-424.