Light-on-a-Chip Group
Electrooptical Engineering

ITMO UNIVERSITY

BGU

Low-contrast photonic hook manipulator for cellular differentiation

Angeleene S. Ang[1,2,3*], Igor V. Minin[4], Oleg V. Minin[4], Sergey V. Sukhov[5,6], Alexander S. Shalin[3], and Alina Karabchevsky[1,2]

[1]Electrooptical Engineering Unit and Ilse Katz Institute for Nanoscale Science & Technology, Ben-Gurion University, Israel
[2]Center for Quantum Information Science and Technology, Ben-Gurion University, Israel
[3]"Nanooptomechanics" Laboratory, ITMO University, Russia
[4]Federal State Unitary Enterprise "Siberian Scientific Research Institute of Metrology", Novosibirsk, Russia
[5]CREOL, University of Central Florida, USA
[6]Kotel'nikov Institute of Radio Engineering and Electronics of Russian Academy of Sciences S (Ulyanovsk branch), Russia
*corresponding author, E-mail: angeleene.ang@gmail.com

June 23, 2018

Abstract

By illuminating an asymmetric cuboid, the photonic hook is generated, a specialized curved photonic jet. In this work, we numerically explored the optical forces generated by the photonic hooks field, and found that the cuboid system can move large objects along a curved trajectory. We considered the interaction of this cuboid in the presence of a backing substrate, as our system is simple enough to be embedded in a lab-on-a-chip platform, and possible applications for cellular differentiation.

Outline

Optical Forces

- Electromagnetic radiation can produce mechanical action on particles[1], and this has been experimentally shown for various applications

[1] L. Novotny and B. Hecht, *Principles of Nano-Optics*

[2] A. Dogariu, S. Sukhov, and J. Senz, Optically induced negative forces, Nat Photon, vol. 7, no. 1, pp. 2427, Jan. 2013.

Optical Forces

- Electromagnetic radiation can produce mechanical action on particles[1], and this has been experimentally shown for various applications
- Through the use of auxiliary structures, it is possible to generate specialized fields, and these fields allow more varied kinds of optical manipulation beyond trapping.[2]

---

[1] L. Novotny and B. Hecht, *Principles of Nano-Optics*

[2] A. Dogariu, S. Sukhov, and J. Senz, Optically induced negative forces, Nat Photon, vol. 7, no. 1, pp. 2427, Jan. 2013.

Optical Forces

- Electromagnetic radiation can produce mechanical action on particles[1], and this has been experimentally shown for various applications
- Through the use of auxiliary structures, it is possible to generate specialized fields, and these fields allow more varied kinds of optical manipulation beyond trapping.[2]
- One example of these structures is the photonic nanojet, a highly-localized, subwavelength, low-divergence beam produced by illuminating dielectric microparticles

[1] L. Novotny and B. Hecht, *Principles of Nano-Optics*

[2] A. Dogariu, S. Sukhov, and J. Senz, Optically induced negative forces, Nat Photon, vol. 7, no. 1, pp. 2427, Jan. 2013.

Optical Forces

Optical forces mathematically obtained using the Maxwell stress tensor, but using the dipolar approximation, the forces are given by[3]

$$\langle F_i \rangle = \frac{1}{2}\mathrm{Re}\left(\alpha \mathbf{E} \cdot \frac{\partial \mathbf{E}^*}{\partial x_i}\right) \tag{1}$$

where α is the complex polarizability.

[3] L. Novotny and B. Hecht, *Principles of Nano-Optics*. United Kingdom: Cambridge University Press, 2006.

[4] B. T. Draine, The Discrete-Dipole Approximation and its Application to Interstellar Graphite Grains, The Astrophysical Journal, vol. 333, pp. 848872, 1988.

Optical Forces

Optical forces mathematically obtained using the Maxwell stress tensor, but using the dipolar approximation, the forces are given by[3]

$$\langle F_i \rangle = \frac{1}{2}\mathrm{Re}\left(\alpha \mathbf{E} \cdot \frac{\partial \mathbf{E}^*}{\partial x_i}\right) \tag{1}$$

where α is the complex polarizability. This is given by

$$\alpha = 4\pi r^3 \frac{\epsilon_p - \epsilon_a}{\epsilon_p + 2\epsilon_a} \tag{2}$$

for a spherical particle.[4]

[3] L. Novotny and B. Hecht, *Principles of Nano-Optics*. United Kingdom: Cambridge University Press, 2006.

[4] B. T. Draine, The Discrete-Dipole Approximation and its Application to Interstellar Graphite Grains, The Astrophysical Journal, vol. 333, pp. 848872, 1988.

Photonic Hook

- Curved photonic nanojets formed by nonspherical dielectric particles[5]

[5] I. V. Minin and O. V. Minin, Diffractive Optics and Nanophotonics. Cham: Springer International Publishing, 2016.

Photonic Hook

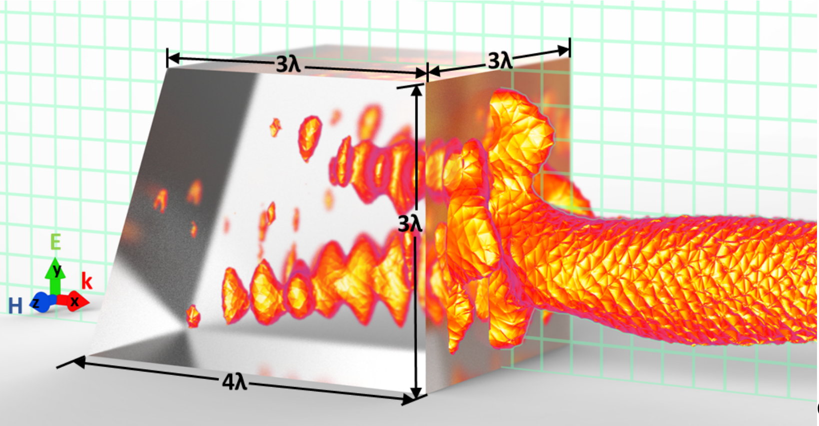
- Curved photonic nanojets formed by nonspherical dielectric particles[5]
- The photonic hook field combines the construction simplicity of the photonic nanojet, as well as the curvature produced by Airy and other self-accelerating beams

[5] I. V. Minin and O. V. Minin, Diffractive Optics and Nanophotonics. Cham: Springer International Publishing, 2016.

Photonic Hook

- Curved photonic nanojets formed by nonspherical dielectric particles[5]
- The photonic hook field combines the construction simplicity of the photonic nanojet, as well as the curvature produced by Airy and other self-accelerating beams
- For this work, we used a asymmetric cuboid made of glass ($n_c = 1.46$, in the optical frequencies). The E-field is polarized along the y axis, propagating along x, illuminated by a plane wave with wavelength of 625 nm. The entire system is embedded in air; the probe particle in this case is a gold sphere with radius of 0.03 μm and complex dielectric permittivity $\epsilon = -11.208 + 1.3184i$.

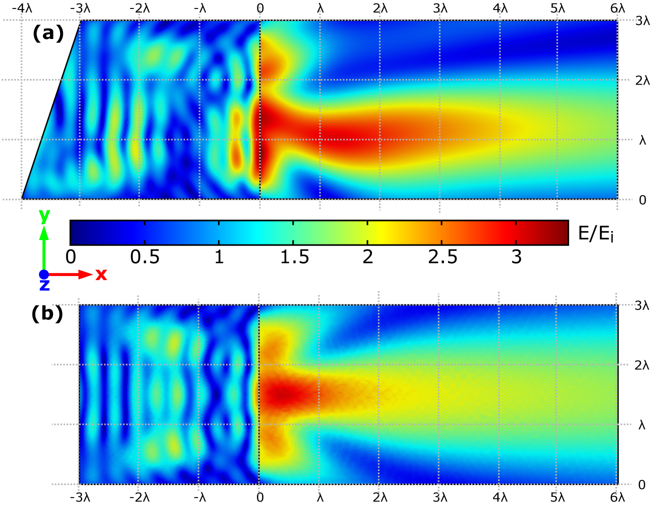
[5] I. V. Minin and O. V. Minin, Diffractive Optics and Nanophotonics. Cham: Springer International Publishing, 2016.



[6]

---

[6] A. S. Ang, A. Karabchevsky, I. V. Minin, O. V. Minin, S. V. Sukhov, and A. S. Shalin, Photonic Hook based optomechanical nanoparticle manipulator, Scientific Reports, vol. 8, no. 1, p. 2029, Feb. 2018.



[7]

[7] A. S. Ang, A. Karabchevsky, I. V. Minin, O. V. Minin, S. V. Sukhov, and A. S. Shalin, Photonic Hook based optomechanical nanoparticle manipulator, Scientific Reports, vol. 8, no. 1, p. 2029, Feb. 2018.

(video slide)

Substrate Implementation

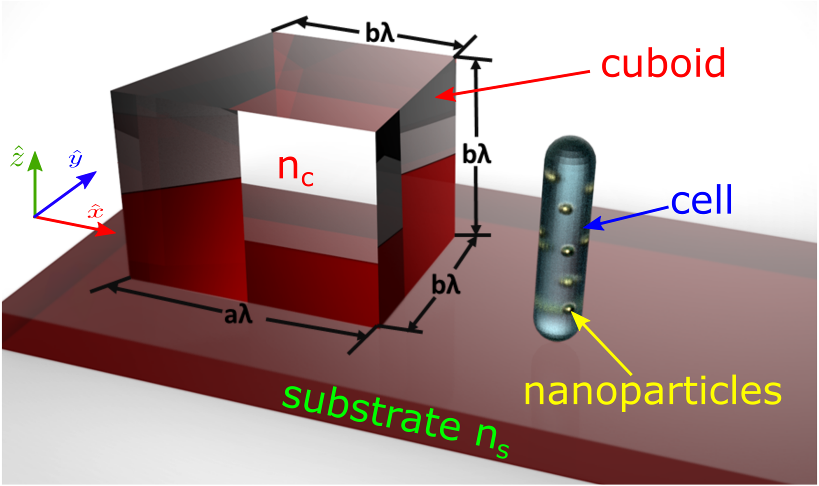
- A factor to consider in the system presented in the previous section is that the background of the cuboid is air. In a realistic system, the cuboid would need to be in contact with another larger substrate.

Substrate Implementation

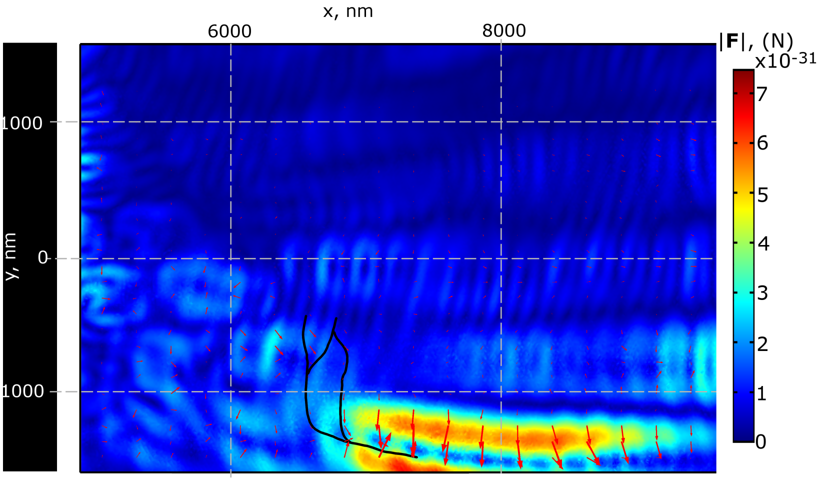
- A factor to consider in the system presented in the previous section is that the background of the cuboid is air. In a realistic system, the cuboid would need to be in contact with another larger substrate.
- This substrate generates its own scattered field, which interferes with the photonic hook field. Our approach to reduce this interference would be to add, for example, a index-matching liquid background (glycerol, $n = 1.47$) to the whole system.

Substrate Implementation

- A factor to consider in the system presented in the previous section is that the background of the cuboid is air. In a realistic system, the cuboid would need to be in contact with another larger substrate.
- This substrate generates its own scattered field, which interferes with the photonic hook field. Our approach to reduce this interference would be to add, for example, a index-matching liquid background (glycerol, $n = 1.47$) to the whole system.
- We emphasize that viscous forces were not considered in the force calculations.



$$a = 7,\ b = 5,\ n_c = 2.15,\ n_s = 1.52$$


x, nm
6000
8000
y, nm
1000
0
1000
|F|, (N)
x10^-31
7
6
5
4
3
2
1
0

Conclusions

- One possible method of using this system in in-vitro application would be using it to guide the cells in a curved trajectory, in order to differentiate between them. However, the equation of the forces has a dependence on the polarizability α

Conclusions

- One possible method of using this system in in-vitro application would be using it to guide the cells in a curved trajectory, in order to differentiate between them. However, the equation of the forces has a dependence on the polarizability α
- If we were to consider guiding the cells without any modification, the force acting on these cells would be nearly negligible, as the index contrast is low. To address this challenge, we introduce gold nanoparticles using cellular uptake to serve as 'handles' to provide the needed material contrast.