Optical Forces and Torques Acting on Non-spherical Metallic Nanoparticles

M. Siler[1], O. Brzobohaty[1], V. Karasek[1], P. Zemanek[1]

[1]Inst. Scientific Instruments of the ASCR, Brno, Czech Republic

Abstract

Metallic nanoparticles (NPs) are nowadays used in various areas of biology, chemistry or physics, e.g. they are used as a heat source causing hybridization of DNA or probes for surface enhanced Raman spectroscopy. Focused laser beams, so-called optical tweezers [1], are widely used to manipulate dielectric particles or even living cells. Optical tweezers may be used as well to manipulate metallic nanoparticles, however, recent experimental studies [2, 3] showed that there is a discrepancy between their predicted and observed behavior. The theoretical models assuming the spherical shape of a nanoparticle predict spatial confinement only for particles with diameter lower than 100 nm while even larger ones were confined experimentally. Noble metals form variously shaped (NPs) during their growth because they crystallize in a face-centered cubic lattice. Various shapes may be prepared by the different chemical conditions of their growth, i.e. sphere, cube, cuboctahedron, octahedron, decahedron or various plates. Figure 1 shows Scanning Electron Microscopy image of particles having nominal diameter 100 nm. Note that no spherical particle is present.

We modeled particles of triangular plate and decahedral shapes using COMSOL Multiphysics® and we solved Maxwell equations in the vicinity of such particles. The particle was placed into electromagnetic field of a laser beam focused by lens having a numerical aperture 0.5 and this field was described by analytical formulas (using angular spectrum decomposition). The problem of electromagnetic scattering was solved using RF Module. Further, we integrated Maxwell stress tensor over a surface enclosing the particle in order to obtain optical force and torque [4].

We performed a parametric study for various particle orientations and locations with respect to the field focus. Some results showing torque acting on decahedral particle tilted by 45 degrees from field polarization and located 5 - 15 µm behind focus are shown in Figure 2a. The negative torque value indicates that particle will rotate with its base into plane given by a beam polarization and a propagation axis. Figure 2b shows the optical force acting on a particle in its stable orientation. If a force curve crosses zero with a negative slope, stable position exists and particle may be optically trapped.

In our contribution we will show that the shape of nanoparticle is a key parameter that enables their optical trapping in optical tweezers. We will show that especially larger flat particles tend to reorient themselves perpendicularly to the beam polarization which strongly decreases their

scattering and enables the optical trapping.

This work was supported by the GA CR (project No. 205/12/P868) and by the EC (project No CZ.1.05/2.1.00/01.0017).

Reference

1. A. Ashkin, et al., Observation of a single-beam gradient force optical trap for dielectric particles, Opt. Lett., 11, 288–290 (1986)

2. P. M. Hansen, et al., Expanding the Optical Trapping Range of Gold Nanoparticles, Nano Lett., 5, 1937–1942 (2005)

3. Lana Bosanac, et al., Efficient optical trapping and visualization of silver nanoparticles, Nano Lett., 8, 1486–1491 (2008)

4. Martin Siler and Pavel Zemanek, Parametric study of optical forces acting upon nanoparticles in a single, or a standing, evanescent wave, Journal of Optics, 13, 044016 (2011)

Figures used in the abstract

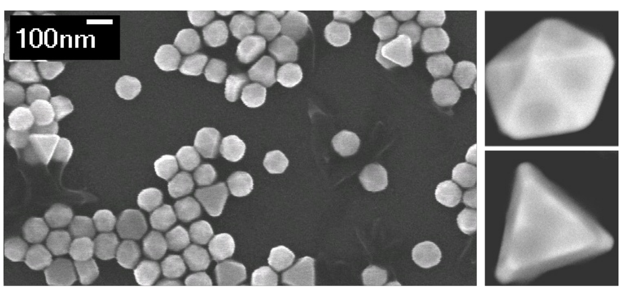

Figure 1: Gold NPs (nominal diameter 100 nm) observed via scanning electron microscope. Right-hand column shows detailed images of decahedral and triangular particle shapes.

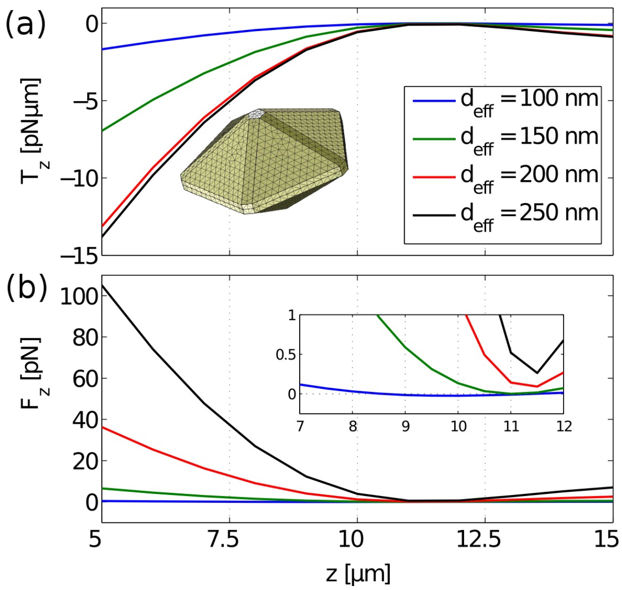

Figure 2: (a) Optical torques acting on a decahedron placed in a distance z behind the focal point. The object is 45 degrees tilted with respect to beam polarization. Different colors correspond to NP effective diameters 100 - 250 nm. (b) Optical force Fz acting on a particle in stable orientation along beam propagation axis. Inset magnifies the negative forces indicating stable trapping.