STABILITY AND HEATING OF A MICRO-PARTICLE TRAPPED BY OPTICAL TWEEZERS: FEM ANALYSIS USING COMSOL MULTIPHYSICS

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Optical tweezers (OT) are scientific instruments that use a highly focused laser beam to provide an attractive or repulsive force (on the order of piconewtons), to physically hold and move microscopic objects similar to tweezers. OT have been originally developed by A. Ashkin 30 years ago and has been particularly successful in studying a variety of biological systems in recent years. The possibility to trap particles into OT is governed by a transfer of momentum between light and matter with the key mechanism being the light scattering. Many methods has been used in order to calculate distribution of scattered light and optical forces. Mostly used are Generalized Lorenz-Mie theory (GLMT), T-Matrix and Coupled dipoles method. However, even Finite Elements Method (FEM) might be used as well. Especially FEM is unique in an ability to combine calculations of optical forces with other physical effects such as heating, temperature distribution, fluid flows, electro-osmotic effects, etc.

Here we use Comsol Multiphysis to study behavior of core-shell particle (i.e. dielectric sphere covered by thin layer of gold) in the optical tweezers. We solve problem of electromagnetic scattering of a tightly focused laser beam on such a structure. Then optical forces are calculated by integration of electromagnetic Maxwell Stress tensor. Figure 1 shows the profile of optical force calculated along the propagation axis of laser beam in optical tweezers ($\lambda_{\text{vac}} = 1064$ nm, focused by water immersion objective NA = 1.2) acting on a core-shell particle (core radius 250 nm, polystyrene, gold layer thickness 25 nm). The force profile was calculated by Comsol by integration of a stress tensor over different surfaces (points) and by a GLMT (curve). We can see that it is impossible to optical trap such a particle since the optical force is always positive and pushes particle along beam propagation. Further, since we are interested in light absorption and consequent particle heating we also calculate temperature profiles near the particle. We obtained both temperature increase of particle surface as well as the inhomogeneity of temperature profile on its surface, see right part of figure 1. This temperature gradient may give a rise to novel force, so-called self-induced thermophoretic force, which may influence particle behavior. Please note that the temperature gradient between particle edges reaches 7 million K/m.

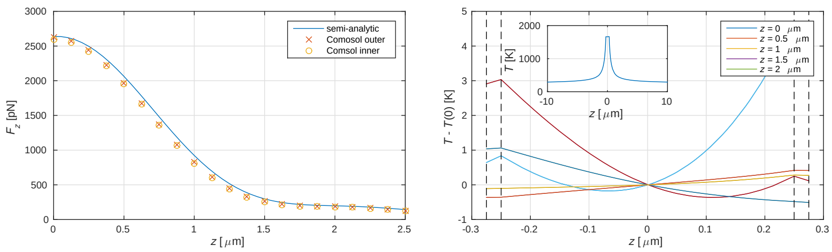

Figure 1: (left) Optical force acting on a core-shell particle in OT calculated by Comsol (points) and by GLMT (curve). (right) Temperature profiles across the particle placed to different positions with respect to the beam focal point. The temperature in particle center is subtracted to show variation of T. Inset shows temperature profile in larger distance from particle placed exactly to the focal point.

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