Simulating the Optical Force and Torque on Metallic Nano-particles

C. Rockstuhl
Friedrich Schiller University Jena, Germany

In this paper we analyze force and torque induced by optical fields on single and coupled silver nano-particles as a function of the wavelength. The geometry of the nano-particles is either a cylindrical one with circular or elliptical cross section or a spherical one.

The most prominent property of those metallic nano-particles is the excitation of the small particle surface plasmon polaritons at well-defined wavelength for which the dielectric constant of the materials takes appropriate values. The resonant oscillation of the free electrons with the frequency of the illuminating wave field causes a tremendous enhancement of the near-field amplitude and the scattering cross section. Such an enhanced scattering might find application in a modified version of a scattering type scanning near-field optical microscope, in which a nano-particle trapped by an optical beam is scanned shortly above the surface of a sample or in a photonic force microscope [1].

For trapping such a particle, all forces acting on it have to be equilibrated. The main forces are the scattering and the gradient force, whereby the first one is proportional to the intensity and the square of the polarizability and it points towards the propagation direction of the laser beam, whereas the latter one is proportional to the gradient of the intensity and the polarizability. If the gradient force is sufficiently strong for compensating the scattering force, the particle is trapped in a position shortly after the waist of a laser beam that has a Gaussian amplitude distribution in the transversal coordinate. For spatial positions deviating from that equilibrium position, the particle is linearly accelerated due to a non-zero net force. In addition to that linear acceleration, non-spherical particles are rotationally accelerated due to a torque and they will align themselves within the wave-field.

In this paper we use the Multiple Mulitipole Method [2] and Mie Theory [3] for a rigorous computation of the wavelength dependent force and torque acting on metallic nano-particles. The observed behavior is physically explained using arguments based on the dipole approximation. It will be shown that different interaction regimes with respect to the plasmon wavelength of the particle exist and specific behavior appears in the different regimes due to a different sign of the polarizability. The conditions for a stable trapping of the particles will be elucidated and the stability of the particles is estimated by comparing the optical force with the Brownian force.

REFERENCES

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