OPTICAL FORCES IN PLASMONIC SYSTEMS

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In spite of the development of laser, our potential to manipulate small particles at a distance is much more limited than our ability to control the motion of the electrons. The interest to develop a powerful, nonmechanical, nondestructive and highly precise technique to manipulate and control small particles has developed a no end researchers in many areas of physics, chemistry and biology. The idea that light may affect the motion of matter has been known since the 17th century when Kepler conjured that comets tails were repelled by a solar light pressure, nevertheless it was Petrus Debye [1] who convinced the scientific community of the possibility to induce important radiation pressure forces on objects such as spheres, when a Mie resonance is tuned. Since 1970 when Ashkin and co-workers demonstrated levitation and trapping of micrometric particles [2], much effort has been devoted to exploring new techniques for trapping and manipulating all kinds of particles. By fashioning proper optical field gradients it is possible to trap and manipulate small particles with optical tweezers or create atomic arrays in optical lattices [3]. Using the evanescent field as the propagating wave it is possible to create an atomic mirror [4], manipulate Mie dielectric and 0.5 m gold particles in the evanescent region of a prism or along channelled waveguides [5]. Although far from the particle resonances light forces are, in general, very small, when the fields are confined in quasi one-dimensional waveguide structures, the coupling of the scattered dipolar field with the waveguide modes leads to a resonant state close to the threshold of a new propagating mode [6] that produces an enhanced resonant radiation pressure [6, 7] and also unusual strong optical interactions between particles [8].

Recently, another type of resonant optical system has caught a lot of attention: namely plasmonic systems, where the free electrons in a metal can be resonantly excited at optical frequencies. This resonant excitation creates extremely strong and confined electromagnetic fields, which can in turn enhance specific chemical interactions such as Raman scattering or fluorescence [9]. Quite surprisingly, optical forces are not very well known in plasmonic systems. This is probably due to the fact that the fabrication of such systems has only been mastered very recently with the advances of nanofabrication. Indeed, plasmonic systems – being it particles of films – have usually dimensions in the sub-100nm range. Plasmonic systems are also extremely sensitive to the illumination wavelength, and the field distribution they produce can dramatically change, depending whether the illumination wavelength corresponds to that of the plasmon resonance or not. Furthermore, by altering the surface, i.e., modifying size, shape and/or the environment of the metal, the conditions for plasmonic resonances can by tailored at will.

The objective of the present contribution is to study some specific effects related to optical forces in plasmonic systems. These include the fact that the strength of optical forces can be changed by tuning slightly the illumination wavelength , as illustrated in Fig. 1. This figure shows that the optical environment around a sub-wavelength cylindrical particle can be dramatically changed by tuning the illumination wavelength at the vicinity of the plasmon resonance of the system. Out of resonance, the field is strongly inhomogeneous, with a minimum just below the particle (Fig. 1.a). When the illumination field excites a surface plasmon on the metallic film, the particle becomes immersed in a strong and homogeneous field (Fig. 1.b)

The interplay between the particle and the metallic interface is actually very subtle. Indeed, for a perfectly flat interface, no surface plasmons can be excited on the metallic film, since the dispersion relation of the surface plasmon is located below the light cone. No free-space propagation vector can therefore excite the surface plasmon. The light scattered by the particle however, creates many different wave vectors, including those required to excite the surface plasmon. This effect is mainly a near-field effect though, and the coupling between the particle and the metallic film strongly decreases as their separation increases.

References

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Figures:

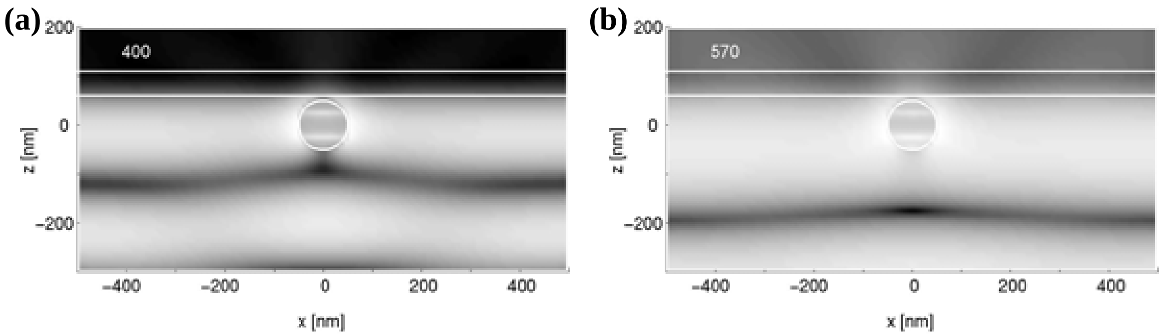

Fig. 1: Electric field intensity distribution of a dielectric particle (index n=1.5, diameter d=100nm) located 10nm below a gold film (thick 50nm) under planewave normal illumination from underneath (electric field in the plane of the figure). (a) Out of resonance (λ=400nm), (b) when a surface plasmon-polariton is excited on the golf film (λ=570nm).