Optical forces on cylinders near subwavelength slits illuminated by either a Gaussian beam or a photonic nanojet: effects of extraordinary transmission and excitation of Mie resonances.

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Abstract

Studies on optical forces on micro- and nano-objects, both in their applications of trapping [1] and optical binding [2], show the sensitivity of these techniques of thermal action on the kinetics of these systems. This involves to increase both the numerical aperture NA and the power of the illuminating beam [3] to control the experiments; the former procedure has obvious limitations for thermal manipulation of biological specimens. The effectiveness of optical trapping increases [3, 4] by illuminating particles through subwavelength apertures in extraordinary transmission [5], namely one excitation of the aperture morphology-dependent resonances (MDR). This allows lower illumination power and its performance is greatly improved [4] when also the Mie resonances of the particles are excited, i. e. their whispering gallery modes (WGM) [6] or localized surface plasmons (LSP) [7]. This enhances the aperture transmittance and localization of light [8-10]. Nevertheless, illuminating with photonic nanojets (PNJ) [11] constitutes an alternative mean to enhance that transmission and localization of light through apertures [12]. PNJs have subwavelength spatial resolution [13] and hence are of great interest of microscopy and detection at the nanoscale [14]. Since, however, they are non-resonant focusing effects, their appearance is not so narrowly constrained by the constitutive parameters and morphology of the particles as Mie resonances are.

We calculate, by means of Maxwell Stress Tensor and a finite element method, optical forces exerted on both dielectric and metallic particles, i. e. infinite cylinders, in or out their Mie resonances, near a subwavelength slit in extraordinary transmission regime. Thus, this latter is illuminated in p-polarization, by either a Gaussian beam or a photonic nanojet. We show the different effects of these particle resonances on the optical forces; namely, while whispering gallery modes under those illumination conditions weaken the force strength, this latter is enhanced by localized plasmon excitation. We show that, the presence of the slit already enhancing by two orders of magnitude the transversal forces of optical tweezers from a beam alone, optical forces additionally incremented by a factor between 3 and 10, at the exit of the aperture, can be reached by illuminating the slit by means of a photonic nanojet. In the first case, we demonstrate a force enhancement, also of binding nature, at plasmon resonance wavelengths on metallic nanocylinders [15]. The role of both scattering and gradient forces are addressed, for the particles at either the exit or entrance of the slit, regarding the bonding or antibonding nature of the overall force on them. In the second case, the presence of the slit can also change the pulling nature of the force that the direct illumination by the nanojet exerts on the small metallic particle in resonance, becoming repulsive at certain lateral positions of this latter [16].

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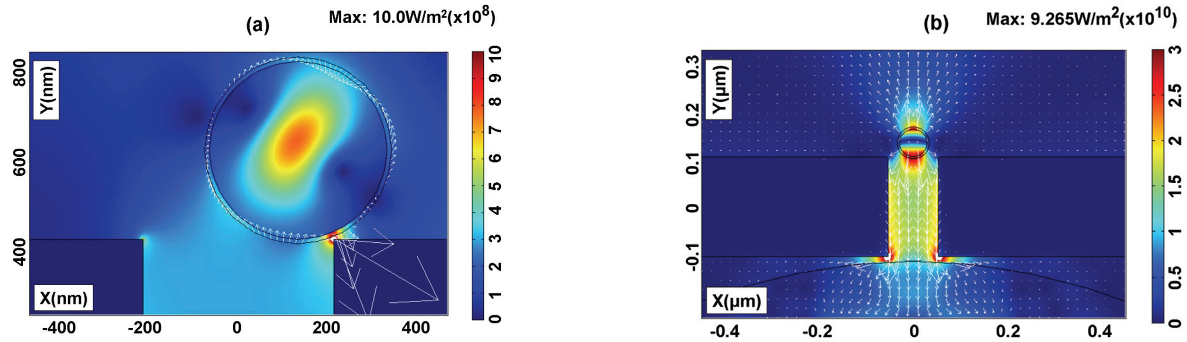
Figures



(a)Example of calculation of optical forces (arrows) and intensity, norm of the time-averaged Poynting vector |<S>| (colors) on a Si cylinder at the exit of a slit practiced through an Al slab. A Gaussian beam impinges on the slit. (b) A slit similar to that of (a) illuminated by a photonic nanojet focused through a silica microcylinder. This mechanism exerts enhanced optical forces on an Ag nanocylinder at the exit of the slit. Map of |<S>| (colors) and <S> (arrows).