Plasmon Resonances of a Prolate Spheroid Nanoparticle Illuminated by a Focused Beam

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Abstract

The interaction of a radially focused beam with a prolate spheroidal nanoparticle is particularly important because it has the potential to produce strong nearfield electromagnetic radiation. Strong and tightly localized longitudinal components of a radially polarized focused beam can excite strong plasmon modes on elongated nanoparticles such as prolate spheroids. In this study, near field radiation from a prolate spheriodal nanoparticle is investigated when it is illuminated with a radially polarized focused beam of light. Nearfield radiation from the nanoparticle is investigated in the absence and presence of metallic layers.

1 Introduction

The interaction of photons with metallic nanoparticles is important to a number of emerging nanotechnology applications due to the large enhancement and tight localization of electromagnetic fields in the vicinity of nanoparticles. In addition, the spectral response of the geometry coupled plasmon resonances of a nanoparticle is tightly distributed, therefore, making it relevant for applications that require high sensitivity. These resonances can be engineered to the desired specifications by utilizing the shape and size of the nanoparticles, as well as the dielectric properties of the surrounding medium [1, 2]. Although experimental studies in the literature have used both collimated and focused beams to excite surface plasmons, until recently the analytical and numerical models in the literature have only used simple plane waves to analyze this interaction.

In this study, the interaction between a radially polarized focused beam of light and a prolate spheroidal nanoparticle is investigated. A new configuration is suggested to further improve the nearfield radiation from a prolate spheroid nanoparticle by creating an image of the localized charge at the tip of the particle by placing the nanoparticle near a metallic layer.

2 Prolate spheroid and radially polarized focused beam

Particles with large aspect ratios can support strong plasmon modes when they are illuminated with longitudinal fields. A radially polarized focused beam has a very strong longitudinal component in the direction of propagation [3]. The strong longitudinal component of radial polarization can excite strong plasmon resonances on a prolate spheroidal nanoparticle with a major axis aligned in the direction of the propagation of the focused beam. To analyze this interaction, a 3D finite element method (FEM) based fullwave solution of Maxwell's equations is used [4]. Radiation boundary conditions are used in FEM simulations. To represent the scattering geometries accurately, tetrahedral elements are used to discretize the computational domain. On the tetrahedral elements, edge basis functions and secondorder interpolation functions are used to expand the functions. Adaptive mesh refinement is used to improve the coarse solution regions with high field intensities and large field gradients. The validity of the method was previously tested with an analytical solution based on generalized Mie theory [5].

In Fig. 1(a) a schematic illustration of a prolate spheroidal nanoparticle and the incident radially polarized focused beam is provided. In this schematic illustration a red arrow illustrates the propagation direction of the beam. The same convention for the propagation direction and nanoparticle orientation is used in the remainder of the simulations. In Fig. 1(b), the total intensity profile is plotted on the xz plane, which passes through the center of the prolate spheroid particle. The incident beam is focused onto the xy plane and propagates in the z direction. The focal point of the incident beam corresponds to the center of the nanoparticle. The wavelength of incident light is 700 nm. The half beam angle of the focused beam is 60°, which corresponds to a numerical aperture of 0.86. $|E(r)|^2$ distribution on the xz cut plane is plotted in Fig. 1(b). All the field intensities reported in this paper are normalized with respect to the intensity of the focused beam at the focal point. Therefore, the quantities reported in the manuscript correspond to intensity enhancement. As shown in Fig. 1(b), a very tightly localized nearfield electromagnetic radiation is obtained at the tip of the prolate spheroidal gold nanoparticle. A very large electromagnetic field enhancement is also observed at the tips of the nanoparticle. The main reason for the large field enhancement at the tips of the nanoparticle is the strong and tightly localized longitudinal component obtained from a radially polarized focused beam. The longitudinal orientation of the focused beam is favorable for the shape and orientation of prolate spheroid nanoparticles with the main axis oriented in the longitudinal direction.

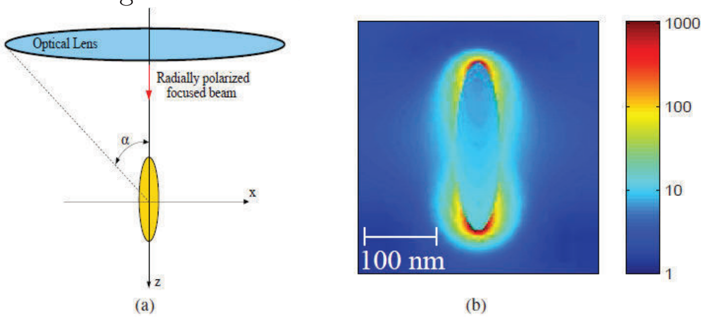

Fig. 1. (a) A schematic illustration of a prolate spheriodal nanoparticle and the incident radially polarized focused beam. (b) $|E(r)|^2$ distribution on the xz cut plane.

3 Impact of a metallic layer

A comparison of the nearfield radiation of a prolate spheroid nanoparticle in the absence and presence of a metallic layer is presented in Fig. 2. The total intensity profile and the frequency response are compared in Fig. 2 for a prolate spheroid nanoparticle in the absence and presence of the metallic layer. All simulation parameters are identical to the simulations in Fig. 1 with the exception of the presence of the 100 nm thick gold layer. The distance between the tip and the metallic layer is varied as shown in Fig. 2. An important parameter that impacts the field strength in Fig. 2 is the distance between the prolate spheroid particle and the gold layer. This distance determines the distance between the electric charges in the dipole.

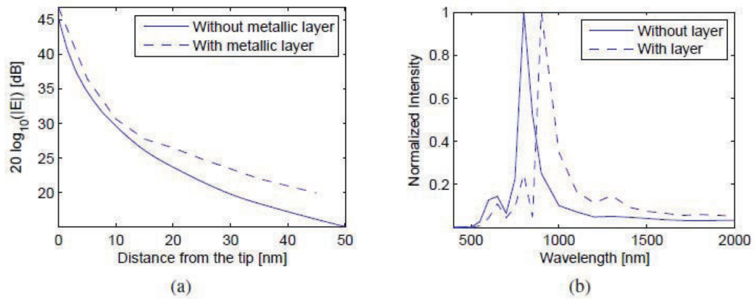

Fig. 2. A comparison of the (a) intensity enhancement and (b) frequency response of a prolate spheroid nanoparticle in the absence and presence of the metallic layer.

4 Conclusion

The interaction of a radially polarized focused beam of light and a prolate spheroidal nanoparticle near a metallic layer was studied. It was found that the presence of a metallic layer increases the near field radiation from the nanoparticle by creating an image of the oscillation charge monopole, and therefore, forming a strong dipole. The distance between the prolate spheroid particle and the metallic layer impacts the field strength of the nearfield radiation. It was also observed that the presence of a metallic layer shifts the resonance of the prolate spheroid toward longer wavelengths.

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