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Near-field polarization distribution of Si nanoparticles near substrate

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Abstract. Structure of the near-field intensity and polarization distributions, the latter is described with the generalized 3D Stokes parameters, of a spherical Si subwavelength nanoparticle in a non-magnetic and non-absorbing media near a dielectric substrate has been studied in detail with the help of the Mie theory and an extension of the Weyl's method for the calculation of the reflection of dipole radiation by a flat surface. It is shown that for the nanoparticle near the substrate the interference effects due to the scattering by the nanoparticle and interaction with the substrate play an essential role. We also demonstrate how these effects depend on the dielectric properties of the nanoparticle, its size, distance to the substrate as well as on the polarization, wavelength and incident angle of the external light field.

Control of the near-field in the proximity of nanostructures is a key to shaping the spatial intensity of light and its polarization distribution at the nanoscale [1]. Near-field being formed by the interference of the incident electromagnetic field with the local field of the nanoparticle strongly depends both on polarization of the incident field and properties of the nanoparticles (their shape and materials). The orientation of the near-field polarization is a key quantity in many theoretical studies on nanooptics, nanophotonic devices and optical sciences in general. Recently, we studied theoretically how the near-field polarization distribution of a plasmonic prolate nanospheroid interacting with a plane electromagnetic wave depends on the polarization and frequency of the incident electromagnetic field [2, 3].

Along with plasmonic nanoparticles, the nanoparticles made of high refractive dielectric or semiconductor materials have recently received considerable attention in the nanophotonics for their ability to control and manipulate the light in the near-field [4, 5]. They allow direct engineering a magnetic field response at optical frequencies in addition to the electric field response in plasmonic structures. As a fundamental building block, the dielectric spherical nanoparticle presents both strong magnetic dipole and electric dipolar responses corresponding to the basic Mie resonances. In many real applications the nanoparticles are often located near a substrate and the influence of the substrate may be

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crucial. In our work, we have studied a structure of the near-field of a spherical Si nanoparticle in a non-magnetic and non-absorbing media near a dielectric substrate with the help of the Mie theory for scattering by a sphere in a homogeneous medium and an extension of the Weyl's method for calculation of the reflection of dipole radiation by a flat surface [5, 6]. The intensity and polarization distributions have been obtained by this method.

We consider two types of substrates with the different absorption coefficients: Im n≈1.5 (carbon) and Im n≈0 (silicon dioxide) (Fig. 1). Fig. 2 shows the distribution of the near-field polarization under the circular polarized incident field for Si nanoparticles without a substrate (left plot), near a quartz substrate (middle plot) and near a graphite substrate (right plot). Significant differences for the distributions near a substrate are due to the Fresnel reflection coefficients, which result in a phase shift in each plane wave in the expansion of the field.

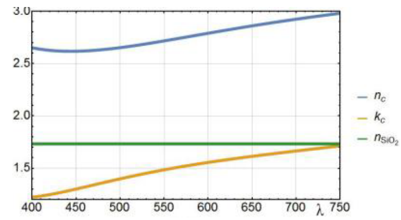

Fig 1. Optical constants of carbon and SiO_2.

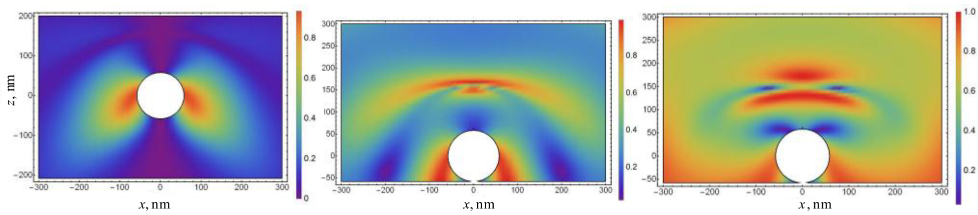

Fig 2. The distribution of the degree of polarization ($P=(I_{max}-I_{min})/(I_{max}+I_{min})$, where I_{max} and I_{min} are the maximum and minimum intensities of the near-field in a specitif point of space around the nnaoparticle) of the near-field under the circular polarized incident field for Si nanoparticles without a substrate (left plot), quartz substrate (middle plot) and graphite substrate (right plot).

In terms of the generalized 3D Stokes parameters, we analyzed the influence of the substrate on the structure of the near-field versus such parameters of the system as the radius and distance of the particles to the surface, polarization, wavelength, the angle of the incident wave, and the dielectric constant of all elements of the system. It is shown that for the nanoparticle near the substrate the interference effects due to the scattering by the nanoparticle and interaction with the substrate play an essential role leading specifically to much more complicated polarization distribution of the near-field by contrast with the case of a nanoparticle in free space filled with a homogeneous medium.

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