Sublayer induced enhancement of electric and magnetic dipole scattering of dielectric nanoparticles

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Abstract. In this paper, we numerically investigate the effect of a low-index sublayer on resonant dielectric nanoparticle placed on a high-index substrate. We show that the scattering cross section depends in a resonant manner on the thickness of the sublayer. In addition, the position of the maxima can be controlled by changing the angle of incidence and polarization of the incident radiation. Finally, we give an example of flexible control of the electric and magnetic dipole responses by changing the angle of incidence and polarization in a system with a subwavelength sublayer.

1. Introduction
One of the key roles in modern silicon nanophotonics is occupied by spherical resonant nanoparticles. Their analytic description, well known as Mie theory, predicted that with a size of the order of 50-100 nm, such particles support both an electric and magnetic dipole responses in visible wavelength range. Nowadays, an increased interest to these particles can be associated with both strong progress in the technology of their fabrication [1] and theoretical research methods, which in turn led to the observation of many interesting effects in many different directions of nanophotonics and nanoplasmonics. For example, based on the powerful analytic approach by Miroshnichenko [2], such effects as demultiplexing of surface plasmon

Figure 1. Geometry of the system. $\theta$ denotes angle of incidence.
2. Substrate induced enhancement of scattering cross section of silicon nanosphere

2.1. Normal incidence

We set the radius of nanoparticle equal to 75 nm, that provides magnetic-dipole (MD) and electric-dipole (ED) responses on 665 nm and 550 nm respectively. For numerical analysis we use T-matrix approach and efficient numerical evaluation of Sommerfeld integrals [5]. In this method the T-matrix of single spheres is defined by the Mie-coefficients. Our first step is calculating $C_{SCA}$ for the normal incident linearly polarized plane waves depending with varying wavelength (in the range of 500 - 800 nm) and the sublayer thickness (0 - 1000 nm). Calculated map (Fig. 2a) reveals several meaningful features. Besides pronounced oscillating nature of the $C_{SCA}$ as a function of sublayer thickness (with the period estimated as $2h_{buf}n_{buf} = \lambda$) polariton by dielectric nanosphere [3] and strong polarization control of electric and magnetic dipole resonances of high-index dielectric nanoparticles placed on a metallic film [4] were shown.

In this paper, we numerically investigate an all-dielectric system consisting of a silicon spherical particle located on a silicon substrate with a silicon oxide sublayer between them (Fig. 1). We show that when a change in the thickness of the sublayer, it is possible to achieve an enhancement of the normalized scattering cross section ($C_{SCA}$). Moreover, this dependence has a resonant character. Another remarkable feature is the dependence of the particle properties in a system with a deep subwavelength sublayer thickness on the angle of incidence and polarization of the exciting light.
Figure 3. Scattering cross sections in the system with 40 nm sublayer thickness as a function of wavelength and angle of incidence. (a, b) Full simulated maps for TE and TM waves. (c, s) Cross sections on ED and MD wavelength for TE and TM waves

one can remark that the first MD and ED maximums are mismatched and achieved with non-zero thickness (Fig. 2b). For example, being approximately the same without the sublayer, ED response dominates MD at 30 nm thickness. At the thickness of 205 nm MD only slightly higher than ED, but we achieve a substantial enhancement of MD with respect to zero thickness sublayer system.

2.2. Oblique incidence
At the next step we discovered the case of oblique incidence primarily resulting in dependence of maximum position of ED/MD responses on polarization (Fig. 2 c, d). However, in both cases shift of maximums in the higher thicknesses region takes place. Therefore MD and ED responses can be selectively excited by appropriate choice of sublayer thickness, polarization and angle of incidence. We demonstrate that by the investigation of the \( C_{SCA} \) as a function of wavelength and angle of incidence for both TE and TM polarizations with fixed sublayer thickens of 40 nm (Fig. 3). The case of TE polarization is notable for the good alignment of ED and MD responses in vicinity of 25 degrees (Fig. 3 a, c). On the contrary, the dipole moments, excited by TM - polarized light, are far apart from each other (Fig.3 b, d - at 15 degrees for ED and 90 for MD).

3. Conclusion
Summarizing, our numerical investigation shows the significant role of a sublayer which provides flexible control over optical properties of resonant dielectric nanoparticles. Specifically,
depending on the thickness, the sublayer may separately enhance scattering by electrical or magnetic resonance, which is clearly seen in Fig. 2 b. Moreover, additional low-index sublayer expand possibilities for control over ED and MD resonances by polarization and angle of incidence.

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