

Toroidal dipole associated resonant forward scattering of light by silicon nanoparticles

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Abstract— In this work we investigate the Kerker-type effect in high-index dielectric nanoparticles for which the third order multipoles give a considerable contribution to the light scattering process. It is shown, that the Kerker-type effect can be associated with the resonant excitation of toroidal dipole moment (third order multipole) and, namely, with the interference of the scattered waves generated by electric, magnetic and toroidal dipole moments of high-index dielectric nanoparticles. We demonstrate theoretically that the interplay between these moments with dominating contribution of toroidal dipole moment can provide strong suppression of the backward light scattering and, simultaneously, resonant forward light scattering.

Resonant electric and magnetic optical responses in all-dielectric nanostructures attract considerable attention because of their important practical applications [1, 2]. Efficient control of the visible light at the nanoscale dimensions is very important when creating optical devices. Dielectric nanoparticles with optical resonant responses can be considered as building blocks for metasurfaces, which can provide efficient control over the phase, amplitude, and directivity of reflected or transmitted light [1, 2].

Here we explore theoretically a realization of the Kerker-type effect [5] in nanoparticles for which the third order multipoles, excited by incident light, give a considerable contribution in the light scattering process. We show that the contributions of electric and toroidal dipole moments into scattered fields can be in phase and interfere constructively, depending on the geometrical parameters of the scatterers, providing resonant enhancement of total electric dipole scattering. In contrast to the anapole state [3], this state may be called *super-dipole*, because, in this case, the total electric dipole scattering considerably increases due to the constructive interference between the electric and toroidal dipole moments [4].

It has been shown using the multipole decomposition method that a constructive interference between toroidal and electric dipole moments of a nanoparticle can be realized in cylindrical and parallelepipedal silicon nanoparticles. As a result, total electric dipole moment (super-dipole) with dominant contribution of the toroidal dipole is resonantly excited in the nanoparticles. It has been found that, due to the interference between electromagnetic fields generated by the super-dipole and magnetic dipole moments of the nanoparticles, the Kerker-type effect can be realized. Thus our work provides important information about the role of toroidal dipole moment resonance in the directive light scattering by high-index dielectric nanoparticles.

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