Looking through *magnetic* glass: controlling nanoparticles scattering via Kerker's conditions and Fano resonances

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Abstract

In this talk I'll overview the importance of the coexistence of magnetic and electric dipole resonances in both dielectric and plasmonic nanostructures for the shaping light scattering via Kerker's conditions and Fano resonances.

Control of light at the nanoscale is demanding for future successful on-chip integration. At the subwavelength scale, the conventional optical elements such as lenses become not functional, and they require conceptually new approach for a design of nanoscale photonic devices. Recently, a new field of optical nanoantennas emerged offering most promising solutions to this problem. Most optical nanoantennas consist of plasmonic nanoparticles due to their ability to capture and concentrate visible light at subwavelength dimensions. But the main drawback in the visible frequency range is their intrinsic losses, which affect strongly the overall performance of plasmonic structures limiting their scalability and practical use.

Recently, several research groups experimentally demonstrated [1-3] that nanoparticles made of low-loss high refractive index dielectric materials offer promising solution for a new generation of nanophotonic devices, also removing many severe limitations of plasmonic structures but exhibiting a strong resonant response at the nanoscale. The key to such novel functionalities of high-index dielectric nanophotonic elements is the ability of subwavelength dielectric nanoparticles to support simultaneously both electric and magnetic resonances, which can be controlled independently [3].

According to the Rayleigh approximation, any single subwavelength element radiates light as an electric dipole, i.e. uniformly in the transverse direction relative to the dipole orientation. Thus, to control any radiation pattern, one needs to have at least two elements and take advantage of their interference. An ideal optical nanoantenna would emit light predominantly in one predefined direction. The simplest structure exhibiting a unidirectional radiation pattern consists of two dipoles separated by a quarter of wavelength with additional $\pi/2$ phase shift between them. It turns out that waves generated by such a dipole pair interfere constructively in one direction and destructively in the opposite direction. However, the interference condition implies that system's size should remain of the order of a wavelength.

The co-existence of both electric and magnetic modes inside a high refractive index dielectric nanoparticle offers new possibilities for advanced manipulating of light scattering. In particular, the interference of radiation patterns of electric and magnetic dipole modes may results in a unidirectional scattering. The amplitude of the electric field produced by an electric dipole is identical in opposite directions while a magnetic dipole produces the out of phase electric field. Thus, by superimposing electric and magnetic dipoles at one point, they result in constructive interference in one direction and destructive interference in the opposite direction, leading to a unidirectional scattering pattern. Recently, such unidirectional scattering patterns of dielectric particles have been experimentally observed in microwave [4] and visible frequency range [5,6]. Such condition is realized when the magnitude of the electric and magnetic dipoles moments are equal. In terms of effective polarizabilities such relation can be considered as a realization of Kerker's conditions. On the other hand, the near-field of an electric dipole is mostly capacitive and of a magnetic dipole is mostly inductive. Thus, when both contributions are equal one may interpret such a relation as an impedance matching condition (with the free space) exhibiting zero backward scattering. Such unidirectional emission can be considered as a realization of an optical Huygens source. Moreover, the sense of unidirectionality can be swapped for different wavelengths due to varying phase lag between both induced dipoles, resulting in asymmetric profiles associated with the Fano resonances.

For spherical shapes the magnetic and electric dipole resonances of high-refractive index particles scale linearly with the particle radius and never approach each other. But, it is possible to vary their relative spectral position by changing, for example, particle's aspect ratio. In particular, it was experimentally demonstrated that two resonances could be overlapped for silicon nanodisks with diameter to height ratio about one [3]. It opens new possibilities to achieve unidirectional patterns (associated with the Kerker's conditions) at the scattering resonances for various applications, including most efficient solar cells.

Remarkably, the unidirectional pattern is still preserved for an arbitrary arrangement of nanoparticles with zero backscattering. Indeed, it can be demonstrated that total radiation pattern of arbitrary placed identical sources is equal to the product of the radiation patterns of the single element and geometry induced form-factors. As a result, if the single element exhibits unidirectional emission, so does an arbitrary configuration of such elements. Since in case of dielectric nanoparticles we are dealing with induced dipole moments, it implies that the excitation conditions should be identical for all particles.

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