Optical multipole resonances of non-spherical silicon nanoparticles and the influence of illumination direction

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Possible Applications

Khorasaniejad M. et al. 


Directional Scattering by high-index nanoparticles


Liu W. et al. 'Ultra-directional forward scattering by individual core-shell nanoparticles.' Optics express 22.13(2014): 16178-16187

Considered System

Parallelepiped, pyramid, and cone with varying height $H$ and diameter of $D = 250$ nm.
Multipole decomposition method

Regular electric dipole moment of the scatterer

\[ p = \int P(r') dr' \]

Toroidal dipole moment, having the same radiation pattern

\[ T = \frac{i\omega}{10} \int \left\{ 2r'^2 P(r') - (r' \cdot P(r')) r' \right\} dr' \]


\[
\sigma_{\text{sca}} \simeq \frac{k_0^4}{6\pi\varepsilon_0^2|E_{\text{inc}}|^2} |p| + \frac{ik_0\varepsilon_d}{c} \frac{T|^2}{6\pi\varepsilon_0|E_{\text{inc}}|^2} + \frac{k_0^4\varepsilon_d\mu_0}{720\pi\varepsilon_0^2|E_{\text{inc}}|^2} \sum |Q_{\alpha\beta}|^2 + \frac{k_0^6\varepsilon_d^2\mu_0}{80\pi\varepsilon_0|E_{\text{inc}}|^2} \sum |M_{\alpha\beta}|^2 \\
+ \frac{k_0^8\varepsilon_d^2}{1890\pi\varepsilon_0^2|E_{\text{inc}}|^2} \sum |O_{\alpha\beta\gamma}|^2.
\]

In the terms of irreducible representation of Cartesian multipoles, toroidal dipole moment is a part separated from symmetrized and traceless magnetic quadrupole and electric octupole moments. It has the same far-field radiation pattern as electric dipole moment and can interfere with it constructively and destructively.

Main results

- Cubes and parallelepipeds

Multipole contributions to the scattering cross-section

- Cubes and parallelepipeds

- Multipole contributions to the scattering cross-section

- Cube and parallelepiped with multipole contributions

- Scattering cross-section versus wavelength for different multipole contributions

- λ = 619 nm, λ = 704 nm, λ = 735 nm, λ = 765 nm, λ = 793 nm, λ = 1229 nm

- Graph showing scattering cross-section in nm² versus wavelength in nm

- Various multipole contributions (TED, MD, EQ, MQ, OCT, Sum Scat, Total Scat (COMSOL))

- Color scales for (V/nm)²
Main results

Cubes and parallelepipeds

Scattering cross-section of nanoparallelepipeds

For parallelepipedal nanoparticles with changed height separated MQ resonance dissapears and becomes merged with TED resonance. If we increase the height of the particle, the resonant region becomes non-resonant and provides side-scattering type of radiation pattern.
Main results

Pyramids and Cones

Multipole Decomposition of SCS of nanop pyramid
Main results

Pyramids and Cones

Influence of the particle height

Evolution of multipole resonances with changing the height of nanopyramid.
Main results

Pyramids and Cones

Multipole decomposition of SCS of Si nanocone

![Graph showing scattering cross-section vs wavelength for different wavelengths and modes](image)

- $\lambda = 526$ nm
- $\lambda = 545$ nm
- $\lambda = 576$ nm
- $\lambda = 759$ nm

- TED
- MD
- MQ
- EQ
- OCT
- Sum Scat

![Mode visualizations for different wavelengths](image)
Main results

Pyramids and Cones

Unsymmetry effect in nanopyramid scattering

2D scattering patterns: the incidence (a,b) from the pyramid base, $\lambda = 516$ nm and 759 nm, (c,d) from the pyramid top, $\lambda = 516$nm and 759 nm. Red (green) contour corresponds to the plane of the incident E (H) polarization.
Summary

- Multipoles up to the third order that were excited by light in parallelepipedal, pyramidal, and conical silicon nanoparticles were investigated.

- Peculiar scattering patterns (even side-scattering) with certain predominant scattering directions can be obtained by tuning the spectral overlap of several multipoles.

- It has been shown that the effect of the asymmetrical multipole response in conical and pyramidal particles depends on the illumination direction.

- Our investigation provides important information about the roles of the high order multipoles in the light scattering by nonspherical nanoparticles and can be applied for the development of the nanoantennas, metasurfaces, coatings etc.
Our published works

The research described in this talk is summarised in my recent publications:


Currently I am doing my research in Ben-Gurion University and ITMO University under the joint supervision of Dr. Alina Karabchevsky (BGU) and Dr. Alexander Shalin (ITMO). We are exploring interesting directions of the research described, such as:

- **Influence of non-air medium** on multipoles excitation.
- **Coupling of two resonant systems**: All-dielectric resonator to molecular resonator which may be described by high order multipole moments (*A. Karabchevsky and A. Kavokin, Nature Sci Rep 6:1-7 (2016)*).
- **Optical properties of all-dielectric metasurfaces** which support high-order multipole excitation.
Our team in Ben-Gurion University of Negev. Thanks for your attention!
**Multipoles’ expressions**

\[ p = \int P(r')dr' \quad (1) \]

\[ m = -\frac{i\omega}{2} \int [r' \times P(r')]dr' \quad (2) \]

\[ T = \frac{i\omega}{10} \int \{2r'^2P(r') - (r' \cdot P(r'))r'\}dr' \quad (3) \]

\[ Q = 3 \int [r'P(r') + P(r')r' - \frac{2}{3}(r' \cdot P(r'))\hat{U}]dr' \quad (4) \]

\[ M = \frac{\omega}{3i} \int \{[r' \times P(r')]r' + r'[r' \times P(r')]\}dr' \quad (5) \]