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Evolution of multipole moments in silicon nanocylinder while varying the refractive index of surrounding medium

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Abstract. Here we use multipole decomposition approach to study optical properties of a silicon nanocylinder in different lossless media. We show that resonant peaks of multipole moments experience red shift, smoothing and broadening. Worth noting that electric multipoles experience bigger red shift than their magnetic counterparts. Our results can be applied to design optical devices within a single framework.

1. Introduction

Dielectric nanophotonics is the one of the most relevant areas in modern optics [1, 2, 3] Subwavelength structures attract special interest due to an opportunity to manipulate light at the sub-wavelength regime. [4, 5, 6, 7, 8, 9, 10, 11] Size, shape, aspect ration, material dispersion and surrounding medium properties can be tuned in order to achieve needed optical properties. [12, 13, 14, 15, 3, 16]

Here we use multipole decomposition approach [17, 18, 19, 20, 21] to study optical properties of a silicon nanocylinder in different surrounding media. Mutual multipole interaction leads to a wide range of opportunities for engineering nanoantennas, [22, 23, 24, 25, 26] sensors, [27, 28] optical filters, [29] energy harvesting devices, [30, 31] and cloaking. [32, 33, 34] Destructive interference between electric and toroidal moment find its application in anapole physics. [35, 36, 37, 38] Multipole decomposition has been also applied in terahertz frequency range [39] and even for studying macroscopic objects. [40]

In this work we study the influence of surrounding media refractive index on the scattering by the silicon nanocylinder in the optical range, as depicted in Fig. 1.

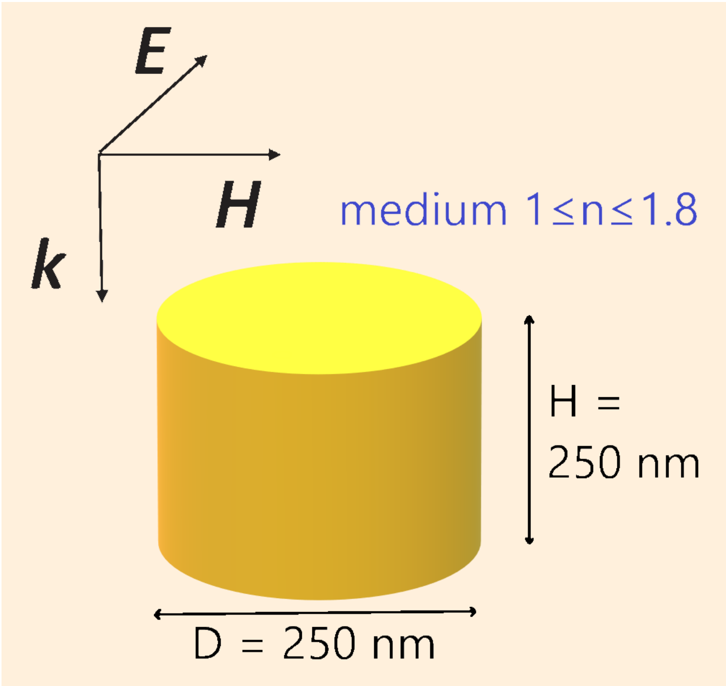

Figure 1. Schematic representation of the considered silicon nanocylinder in a lossless medium under a plane wave illumination.

2. Results and Discussion

In Fig. 2 we show multipole decomposition spectra for the silicon nanocylinder in 3 different media. Fig. 2(a) shows the multipole decomposition spectrum for the cylinder in the air. One can note two resonant peaks of electric quadrupole (EQ) excitation, one peak of magnetic quadrupole (MQ) and one peak of total electric dipole (TED). In addition, resonant peaks between $\lambda = 650$ nm and $\lambda = 750$ nm are relatively small.

Resonant peak experience broadening and smoothing as n raises up to 1.4, as can be seen in Fig. 2(b). For $n = 1.8$ in Fig. 2 (c) these effects become even more stronger providing the approximately equal contributions over the entire spectrum. Worth noting that electric multipole moments experience bigger red shift then magnetic ones.

As we show, multipole response in the silicon particle can be tuned by changing a refractive index of surrounding media. Such tuning can be widely applied to design optical devices and samples based on dielectric components at the nanoscale.

3. Conclusion

In this work we studied the optical properties of dielectric nanocylinder in different dielectric media. We showed that overall scattering decreases due to the lower optical contrast. Using the multipole decomposition approach we showed that electric multipole moments resonant peaks experience stronger red shift than their magnetic counterparts as media refractive index raises. In addition, all multipole resonances experience broadening and smoothing.

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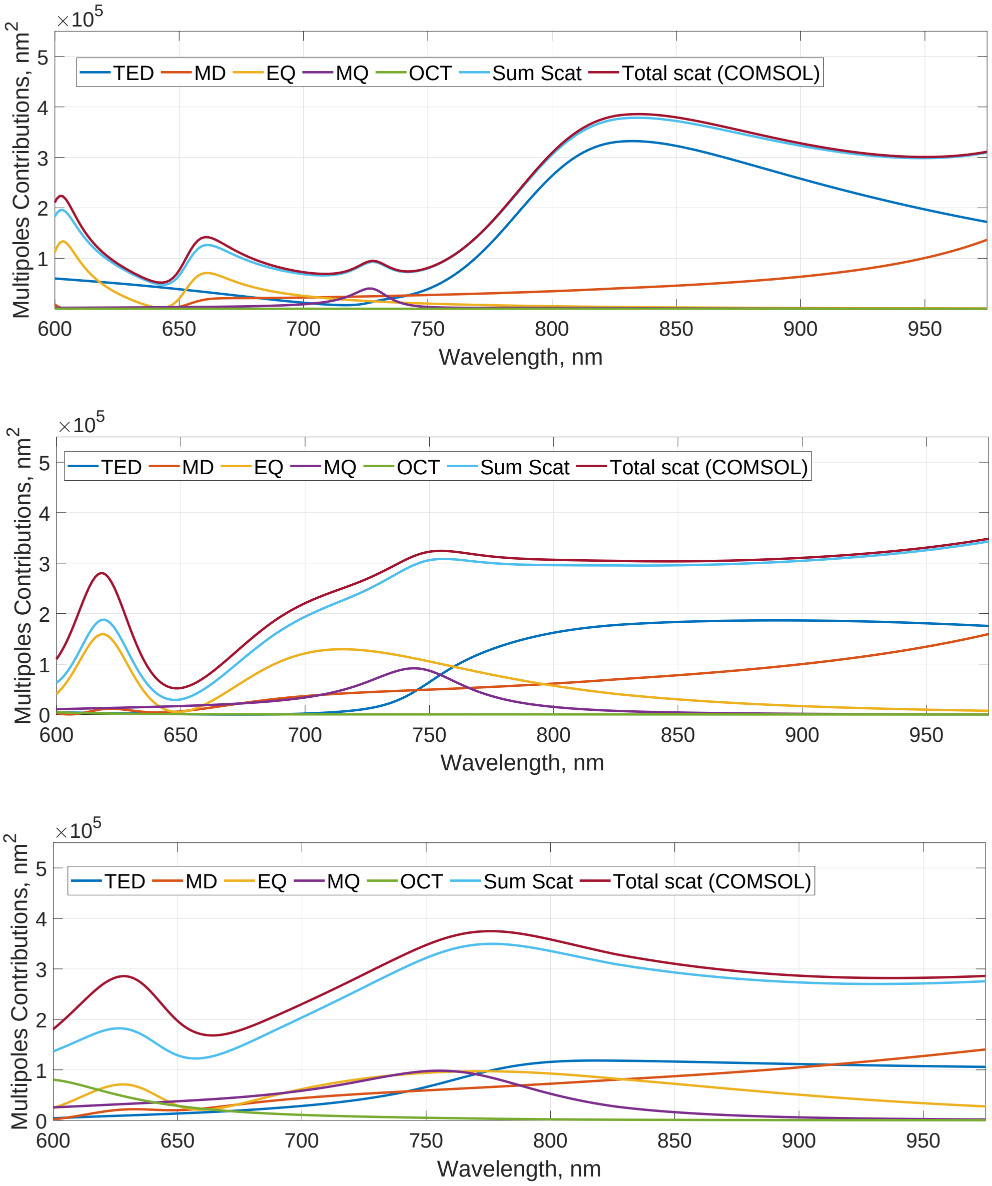

(a)

(b)

(c)

Figure 2. Spectra of the scattering cross-section and corresponding multipoles' contributions calculated for a silicon nanocylinder with height $H = 250$ nm and base radius $R = 125$ nm (a) in air (b) in medium with $n = 1.4$ (c) in medium with $n = 1.8$.

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