More effective than a "super" absorption in spherical nanoparticles

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There is a theoretical limit for absoption by a subwavelength bulk spherical partical. To overcome this limit we applied a widely used "super" design pattern for a multilayered particle which superpose several electric and magnetic mulitpole resonances. We used a straightforward approach to evaluate several designs from realistic materials. However, we found that due to dimension effect it can be preferable to use a properly disigned particle of smaller size with only a dipole response in order to reach the best absorption efficiency.

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Mie theory [TODO] describes interaction of an electromagnetic wave with a spherical particle. Inspite of its long history lasting over a century it is still of great interest our days [TODO] . Development of Mie theory [1, 2] made it possibile to explore properies of multilayer spherical particles [TODO]. Such particles has various applications in cancer treatment [TODO 5,6 from Ovidio draft] and medical diagnostics [TODO 7 from Ovidio draft], cloaking devices [3, 4], solar cells ... [TODO].

The problem of scattering from a multilayered cylinder and a sphere was investigated in great detail with Fan et al. [Fan-PRL, Fan-APL]. In his work he defined a "super" scatterer as a subwavelength object having a scattering cross section that far exceeds the single-channel limit of the maximal total angular momentum involved. From spectral point of view this means the superposition of several electric and/or magnetic resonances.

There is a similar problem to design highly absorbing subwavelength particles. Tribelsky has derived [TODO] a theoretical limit of a maximum absorption value for a single channel. As a result the scattering coefficient (as defined in Mie theory [TODO Bohren Huffman]) for the used angular momentum become limited with 1/4 in case of largest possible absorption. To overcome single-channel limit we tried to use similar approach and to tune together several absorption resonances.

We used a triple layered $Si/Ag/Si$ spherical particle with experimental material parameters from Palik [TODO] illuminated with a plane wave (Fig. TODO). To optimize width of each layer we implemented [link to GitHub] adaptive differential evolution [5] algorithm named JADE [6]. All the details on the optimization procedure can be found elsewhere [4]. Initially we tried to maximize contibution of several multipole resonances at a given wavelentgh $\lambda = 500$ nm. However, best results were obtained with the optimizer set to find maxima of the absorption efficiency factor $Q_{\rm abs} = C_{\rm abs}/2\pi R_{\rm total}^2$, where $R_{\rm total}$ is the outer radius of the particle and $C_{\rm abs}$ denotes absorption cross-section. This way, the efficiency is defined as absorption cross-section normalized to the geormetrical cross-section of the particle.

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[1] W. Yang, Applied Optics **42**, 1710 (2003).
[2] O. Peña and U. Pal, Computer Physics Communications **180**, 2348 (2009).
[3] X.Wang, F.Chen, and E. Semouchkina, AIP Advances **3**, 112111 (2013).
[4] K. Ladutenko, O. Peña Rodríguez, I. Melchakova, I. Yagupov, and P. Belov, Journal of Applied Physics **116**, 184508 (2014).
[5] R. Storn and K. Price, Journal of Global Optimization **11**, 341 (1997).
[6] J. Zhang and A. Sanderson, Evolutionary Computation, IEEE Transactions on **13**, 945 (2009).

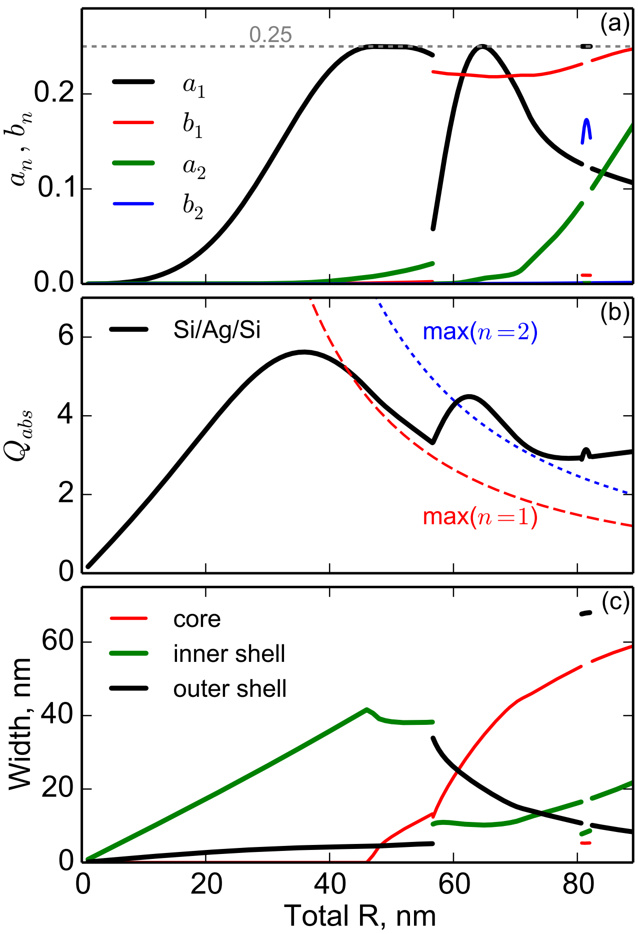

Figure 1. Optimized designs overview at working wavelength $\lambda = 500$ nm. (a) Scattering coefficients (b) Absorption efficiency with best value at total R=36 nm and Ag/Si design (zero sized core) and "super" designs at R=63 nm and R=81 nm. (c) Used layers width, for total $R < 45$ nm the core width was optimized to be zero, the design become bi-layer Ag/Si particle.

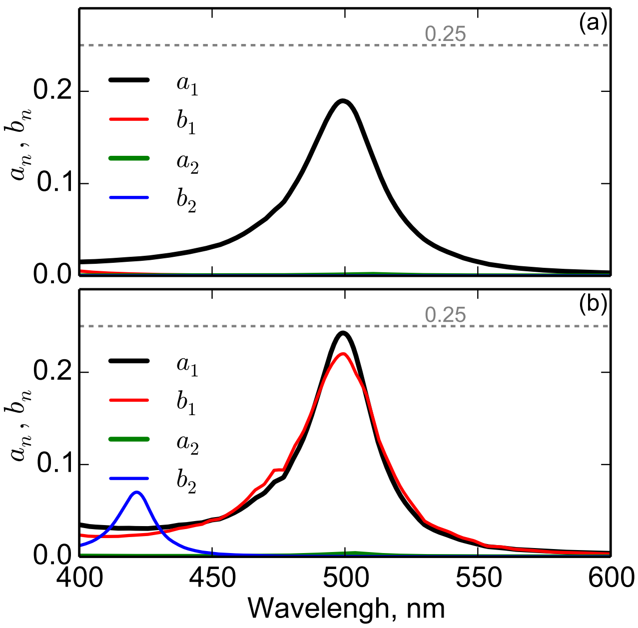

Figure 2. Expansion coefficients spectra of (a) efficient and (b) "super" design.

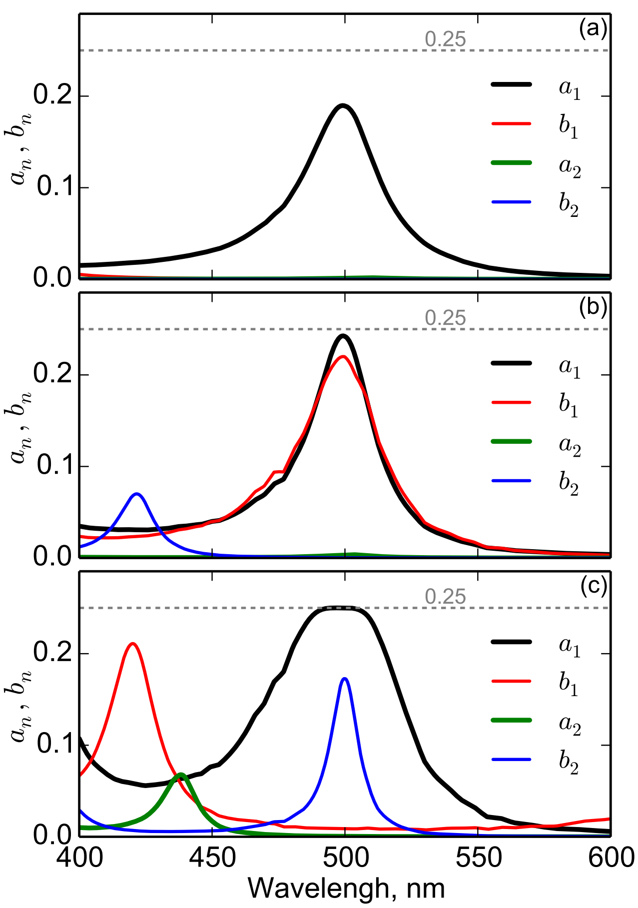

Figure 3. (Or we can use) Expansion coefficients spectra of (a) efficient and (b-c) "super" design.

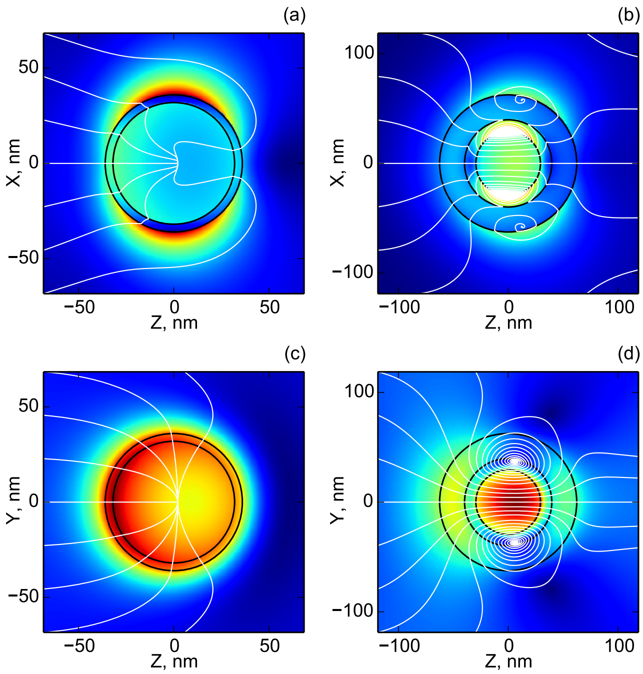

Figure 4. (Main field figure. The following figures are given for reference and should be removed from the manuscript). Electric field for efficient (a,c) and "super" (b,d) designs in E-k (a-b) and H-k (c-d) planes.

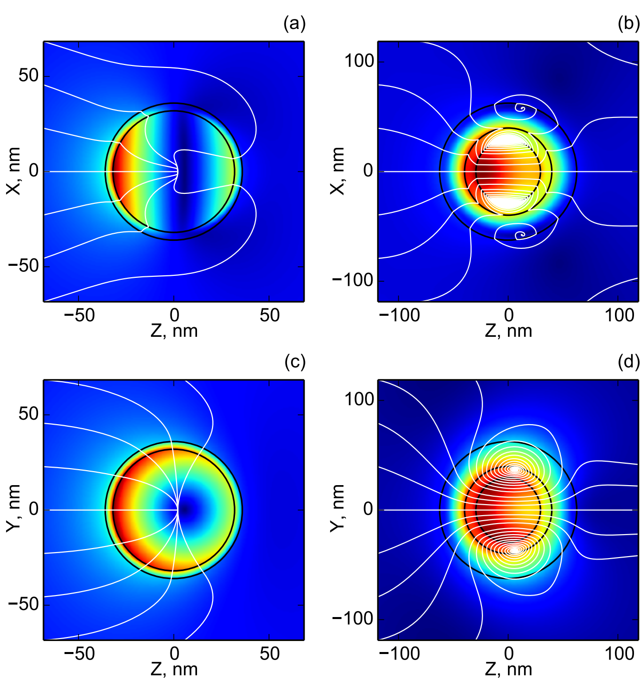

Figure 5. Same as Fig. 4 for magnetic field.

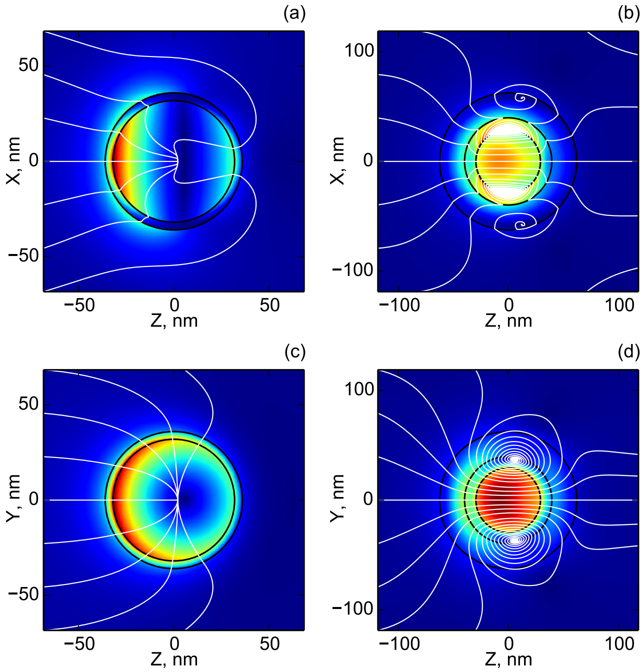

Figure 6. Same as Fig. 4 for Poynting vector.

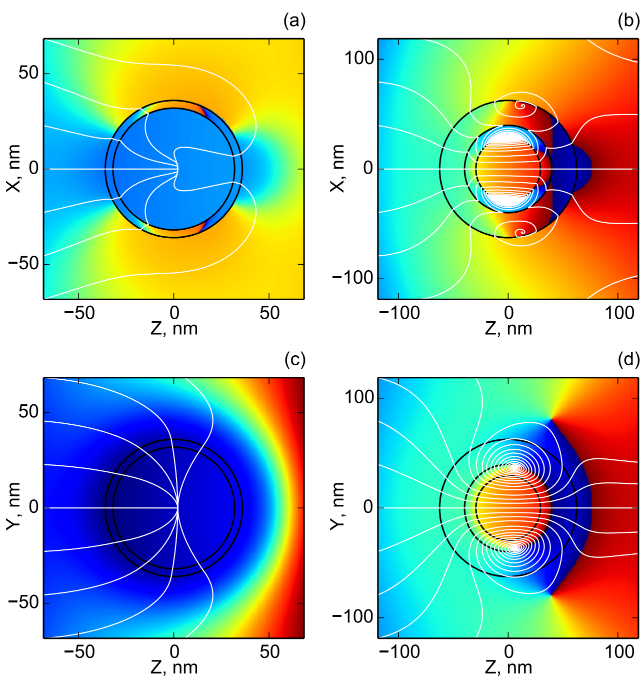

Figure 7. Same as Fig. 4 for phase of the electric field (x component).

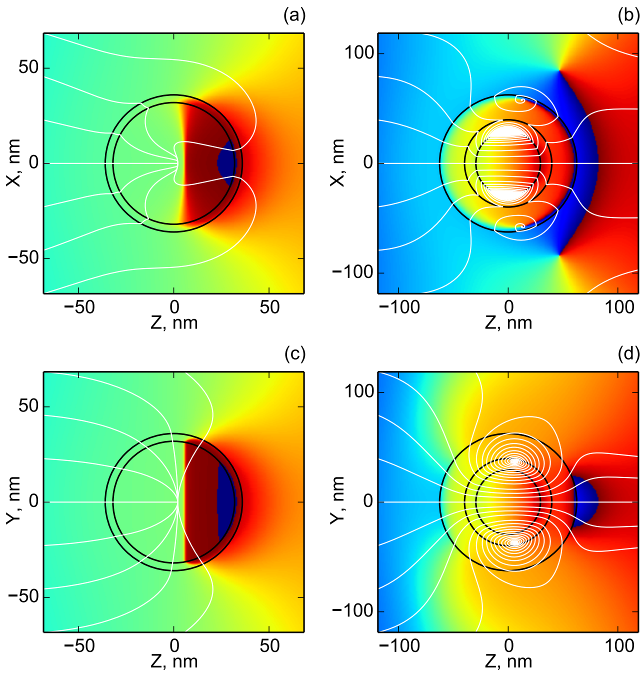

Figure 8. Same as Fig. 4 for phase of the magnetic field (y component).