Optimized refractive index of subwavelength spheres for maximum scattering cross-section and zero backwards scattering

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Zero backward scattering from dielectric spherical particles had been theoretically predicted by Kerker *et.al.*[1] decades ago. The first experimental confirmations of Kerker's proposal concerning unconventional forward–backward scattering asymmetry have been reported very recently[2-4]. Nowadays, particles showing zero backscattering with large scattering cross section in forward direction are catching great attention of scientists in various fields due to their unique properties, such as the efficiency enhancement as light diffusing elements in solar cells. As we will show, there is an optimal particle refractive index at which, the scattering cross section of a single sphere is maximum. The motivation of this work is that from the theoretical point of view, we find the best materials of spherical particles for having large forward diffusion without backward scattering of light.

Magnitude of backscattering is defined by the backscattering efficiency $\boldsymbol{Q_b}$[5]. For materials having $\boldsymbol{Q_b} = 0$ at several different wavelength $\boldsymbol{\lambda}$, we choose always the one corresponding to larger extinction cross section $\boldsymbol{Q_{ext}}$. And turns out such wavelength position is also where the first Kerker condition of the particle occurs. Notice that calculations are done under assumption of the absence of absorption within the entire calculated spectrum of wavelength, i.e. $\boldsymbol{Q_{ext}}$=$\boldsymbol{Q_s}$. As a result, we find out that when size parameter ($\boldsymbol{y = 2\pi a m/\lambda}$) is about 2.75, spherical particles with $\boldsymbol{m}$ = 2.47 have zero backscattering and the largest scattering cross section $\boldsymbol{Q_S}$ under the first Kerker condition. The examples of non-absorbing materials given in this work are diamond, titanium dioxide (TiO_2) and strontium titanate ($SrTiO_3$). The extinction and scattering cross-section of Si particles are also calculated, as an example of materials with absorption in the regime of visible light. And it is demonstrated that the main Mie resonances within the calculated light spectrum are attributed to the electric and magnetic dipoles.

References:

[1]. M. Kerker, D. Wang, and G. Giles, *J. Opt. Soc. Am.*, **73** (1983) 765.

[2]. J.M. Geffrin, B. García-Cámara, R. Gómez-Medina, P. Albella, L.S. Froufe-Pérez, C. Eyraud, A. Litman, R. Vaillon, F. González, M. Nieto-Vesperinas, J. J. Sáenz, and F. Moreno, *Nat. Commun*. **3** (2012) 1171.

[3]. S. Person, M. Jain, Z. Lapin, J.J. Sáenz, G. Wicks, and L. Novotny, *Nano Lett.*, DOI: 10.1021/nl4005018 (2013).

[4]. Y.H. Fu, A.I. Kuznetsov, A.E. Miroshnichenko, Y.F. Yu, and B. Luk'yanchuk, *Nat. Commun.* **4** (2013) 1527.

[5]. C. F. Bohren, and D. R. Huffman, *Absorption and Scattering of Light by Small Particles* (John Wiley and Sons) (1983).

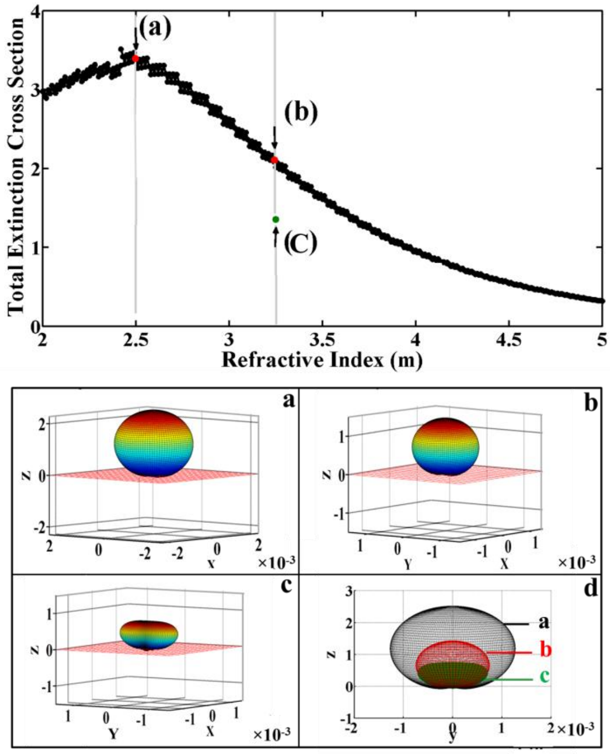

Figure 1. Extinction cross-section as a function of the refractive index. The total extinction cross-section of different materials is plotted at constant size parameter $y = 2\pi am/\lambda$ =2.75. The 3-dimentional differential scattering images of three selected data points ***a***, ***b***, and ***c*** are also shown. The projection of the yz-plane of points ***a***, ***b***, and ***c*** is shown in the inset ***d***.