Studying light concentration in a dimer of semiconductor nanoparticles for all-optical devices

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Abstract. Scattering by subwavelength dielectric nanospheres can have interesting directional effects in the case of accomplishing Kerker's conditions. We have taken advantage of these conditions to design a dimer of semiconductor nanoparticles where an important contrast can be achieved in their gap, due to the directionality and the interferential interaction of the scattered fields.

Light scattering in subwavelength spheres ($R/\lambda<<1$) is described by Mie theory. In the case of dipole-like particles, it is enough to use the first two Mie coefficients (a_1 and b_1, regarding dipolar electric and magnetic effects respectively). Starting from that point, Kerker and co-workers [1] reported that particles can present a lack of scattering in the forward or the backward directions, if the scattering coefficients accomplish certain conditions, known as minimum-forward (MF) and zero-backward (ZB) conditions or Kerker's conditions:

$$\begin{aligned} &\mathrm{Re}(a_1) = -\mathrm{Re}(b_1)\,;\, \mathrm{Im}(a_1) = \mathrm{Im}(b_1) \\ &a_1 = b_1 \end{aligned} \quad (1)$$

Kerker's conditions can be satisfied in nanoparticles made of several usual semiconductor materials, such as Silicon, Germanium, TiO_2, GaAs, etc., in the visible range [2, 3]. Using two different nanoparticles with different sizes, we are able to accomplish each Kerker's condition at each nanoparticle at the same wavelength. Then, we have proposed a dimer of silicon nanoparticles [4] presenting such a combination of directional scattering in the visible range. This anisotropic scattering, as well as the interferential effects between the scattered fields, can produce an intense maximum or a deep minimum of the light intensity in the gap region. As Kerker's conditions are very dependent on the wavelength, a slight shift of the incident wavelength can perturb the satisfaction of the conditions producing a drastic change of the light intensity in the gap (Fig. 1).

This effect has been explored considering several semiconductor materials, sweeping sizes and distance between nanoparticles, in order to optimize the contrast between the states fulfilling or not the Kerker's conditions. Figure 2 shows the example of TiO_2 nanoparticles illuminated with a light beam of 543 nm. As it can be seen, for a light impinging first on a nanoparticle satisfying the ZB and then on MF nanoparticle (case 180º), strong interferential effects appear. The anisotropic scattering distribution of the nanoparticles enables this strong interaction, even producing that the scattered fields null each other. Sweeping wavelength in the vicinity of the target one, the Kerker's conditions do not apply anymore, and a strong contrast can be achieved with a small change in wavelength.

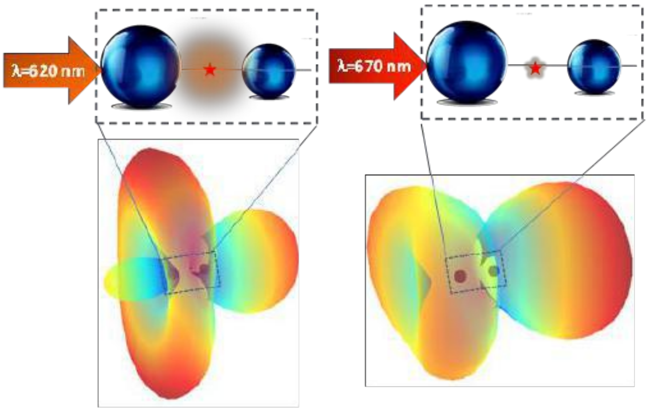

Figure 1. Up: Scheme of the configuration of a silicon dimer with nanoparticles of radius 96 and 82 nm and a gap distance of 360 nm. Down: spatial distribution of the scattered fields in the far-field region in each case.

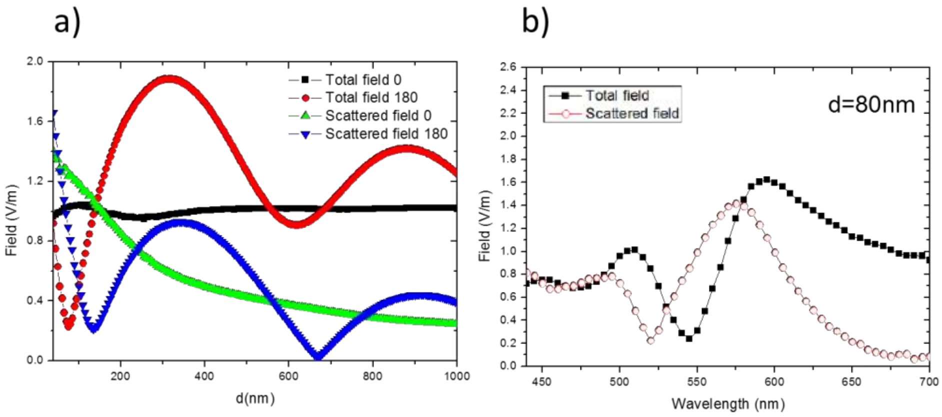

Figure 2. a) Scattered and total field of a dimer of TiO_2 nanoparticles (R_1=78 and R_2=93 nm) at 543 nm as a function of the gap distance, considering the two possible impinging directions. b) Scattered and total field of a dimer of TiO_2 nanoparticles at the middle point of the gap for a distance of 80nm as a function of the wavelength and considering the 180º configuration (as in Figure 1). Interferential effects lead to a remarkable 20% to 160% of incident field contrast around 550 nm.

New studies regarding polarization effects are currently on the way.

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