Near-field patterns in two dimensional arrays of gold nanorods supporting geometric resonances

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Abstract

Arrays of metallic nanoparticles have been found to exhibit attractive properties such as sharp peaks of extinction[1] and field enhancements higher than the ones exhibited by localized surface plasmon resonance (LSPR) of single nanoparticles[2]. These features arise from the coupling with the LSPR and the diffraction orders of the arrays, and can be exploited in different applications such as sensing[3], enhanced Raman scattering, etc. Therefore, a deeper understanding on these phenomena and the underlying near-field distribution is of interest to enhance the performance of the arrays.

In this work, we have investigated the far and near field responses of two dimensional arrays of gold nanorods on glass by means of extinction spectra (figure 1), scanning near field optical microscopy (SNOM) and numerical simulations using FDTD techniques (the model uses the morphological data obtained from scanning electron and atomic force microscopies). We have fabricated by e-beam lithography a set of arrays of nanorods with different width, length and height (see example in Fig. 1). Every type of nanorod sustains a LSPR in the same range of wavelengths than the laser used for the SNOM measurements (658 nm). As we want to distinguish between the contribution to the near field distribution that is induced by the interaction LSP – array and that produced by the LSP itself, we have chosen different array periodicities in order to place the Rayleigh anomaly (RA) inside or outside the LSPR region, respectively. The near field microscopy has been carried out by exciting the samples in transmission and by probing the near field with a fluorescent particle of 100nm diameter. We have scanned the samples in a horizontal plane about 40nm above the structures, as well as in the vertical plane which contains the small axis of the nanorods. Different polarizations of the incident light were used for both far and near field experiments.

Our results show that the collective geometrical response induces a complex redistribution of the near-field distribution. In fact, we pinpoint that the vertical component of the electric field can play an important role in the resulting field pattern, a significant difference with previous theoretical works that only considered in-plane components[4]. For instance, the z-component is rapidly delocalized when approaching the wavelength of the RA, leading to a characteristic profile of the electric field with intense lobes, as illustrated in Fig. 2. Moreover, we show that the intensity of this component depends on the spectral position of the LSPR in a drastic manner. Our results offer a deeper insight on the interplay between individual and collective resonances, which can be of interest for tailoring the near field distribution involved into the designing of sensing applications, and more generally, into the 3D electromagnetic shaping of nanostructures.

References

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Figures

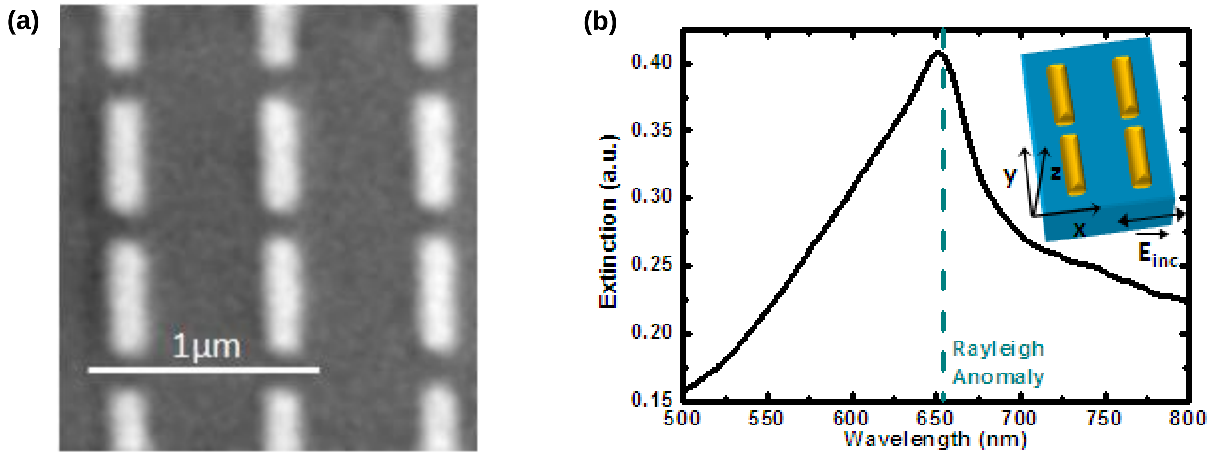

Fig. 1: (a) SEM picture of an array of nanorods. b) Experimental extinction spectra of the array shown in (a). The vertical dashed line shows the wavelength of a Rayleigh anomaly. Inset: the schema represents the array of nanorods and the definition of the coordinate system. The incident light is polarized along the double arrow labeled E_{inc}.

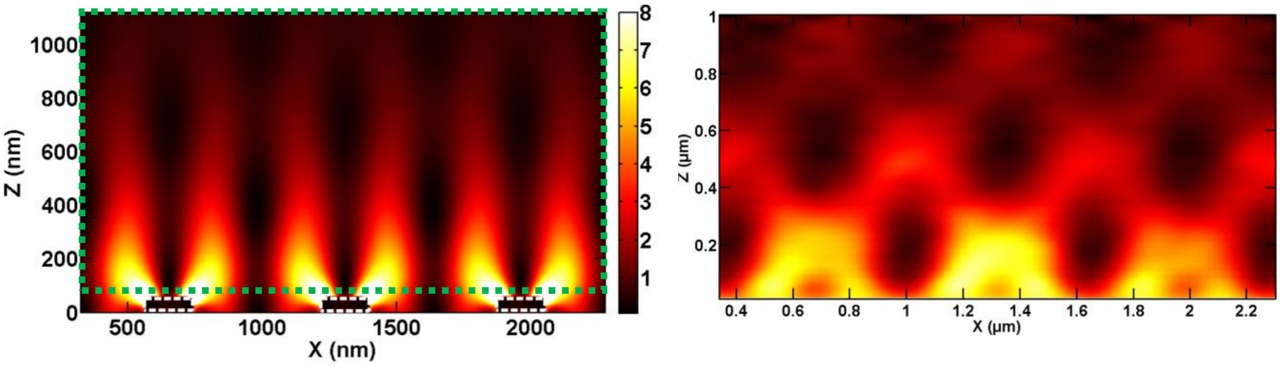

Fig. 2: Near-field distribution at a wavelength close to the RA. The zone corresponds to the x-z plane crossing the nanorods on their center. Left: Numerical result. z=0nm is the surface of the substrate. The white dashed rectangles represent the cross-sections of the nanorods. Right: Experimental SNOM image which corresponds to the region shown by the green dashed rectangle on the numerical result. On the experimental image, z=0 is actually about 40nm above the nanorods.