Interplay between linear antenna modes and gap cavity modes within a single flat-gap nanoantenna

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Linear wire antennas commonly used at radio frequencies[1] are very effective structures to scale antenna properties down to optical frequencies. A combination of metallic rods separated by a few nanometers, in so-called gap-antennas, produces strong near fields at the gap[2]. Here we investigate the resonant behavior of such structures formed by flat interfaces at the gap and separation distances smaller than 1 nanometer. We perform electromagnetic simulations of the extinction and near-field properties of the flat-gap antennas using the boundary element method (BEM)[3].

The extinction cross section is dominated by a clear maximum (Figure 1a) of dipolar nature, as revealed by the distribution of the near field (Figure 1c). Other weaker peaks appear at shorter wavelengths. As expected from previous work, decreasing the gap down to distances of a few nanometer results in a clear redshift of the dipolar peak. However, in contrast to previous work for metallic spheres[4], we find a saturation of the redshift for distances smaller than approximately one nanometer. Similarly, the strength of the different extinction maxima also saturates. We connect this distinctive behavior with the dimensionality of the antenna flat-gap that allows the formation of a new set of very localized cavity modes.

The spectral behavior of the near fields at the gap center present a more complex structure, with numerous peaks as illustrated in Figure 1b. Both the position and strength of the maximum field enhancement show a non-trivial dependence with separation distance. We interpret our results in terms of the coexistence of two different sets of resonant plasmonic modes. The maxima in the extinction cross section correspond to charge oscillations along the antenna axis, in analogy to the behavior of classical wire antennas at radio frequencies. Nevertheless we notice that at optical frequencies one needs to consider the excitation of plasmons[5] and how they are influenced by the gap. The spectral behavior of the near fields at the gap show considerably more peaks than the extinction, which we explain by the excitation of the second set of modes, associated to the gap. Such gaps can be seen as metal insulator metal structures supporting cavity modes[6] in the horizontal direction, i.e. perpendicular to the antenna axis. These plasmonic modes have no equivalence in classical antenna theory. The interplay between the two different types of modes helps to explain not only the nature of the different peaks, but also their strength: stronger near fields are observed when modes along the rod axis and horizontal cavity modes in the gap coincide in their spectral positions.

Perspectives for future work include the use of experimental dielectric constants, instead of a Drude description as presented here, and the consideration of quantum effects for the smallest separation distances at the gap [7].

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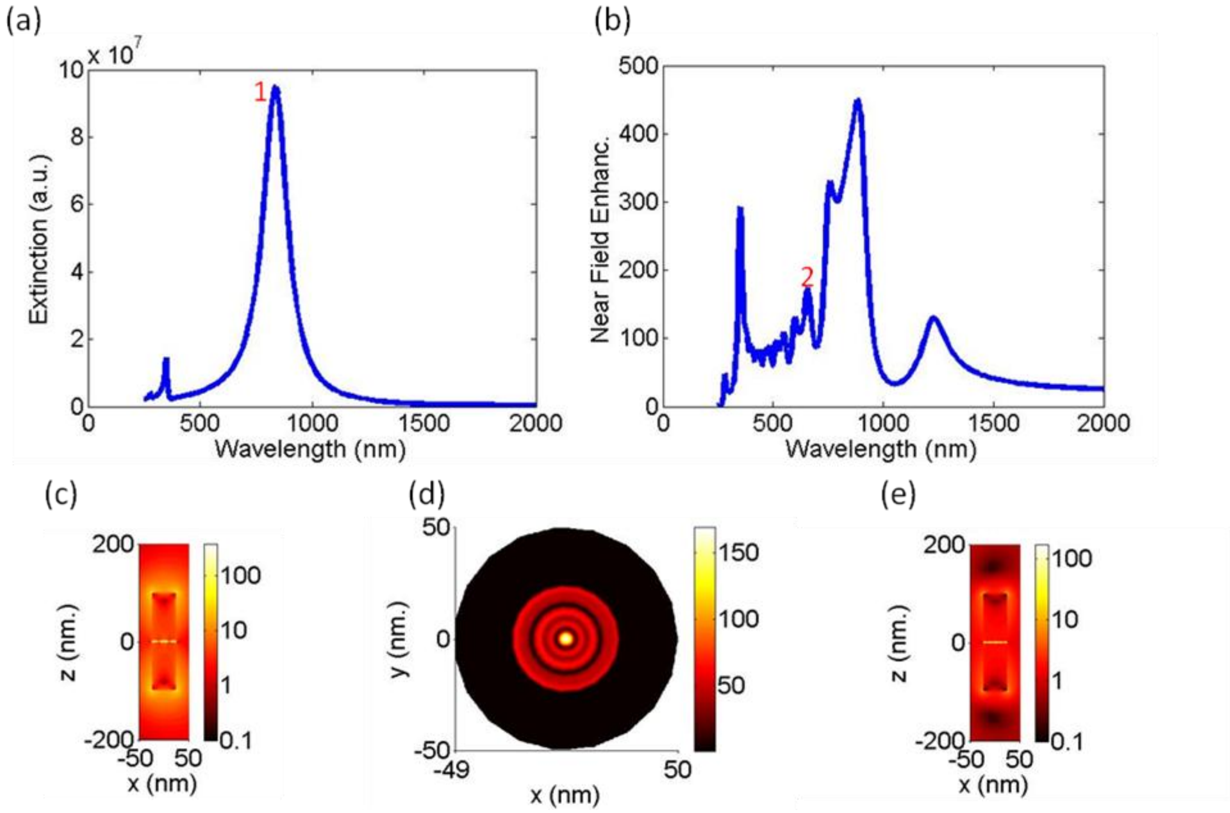

Figures 1: (a) Extinction spectra and (b) near field enhancement at the gap center, for a gap of 4 atomic units. (c) Near fields in a vertical plane for the resonance marked 1 in (a). (d,e) Near fields in a vertical (e) and an horizontal (d) plane for the resonance marked 2 in (b). Notice how the near-field spectrum in (b) peaks up at the position of the extinction maxima (a).