Coil-type Fano Resonances: a Plasmonic Approach to Magnetic Sub-diffraction Confinement

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Abstract: Matrices of nanodisk trimers are introduced as plasmonic platforms for the generation of localized magnetic hot-spots. In Fano resonance condition, the optical magnetic fields can be squeezed in sub-wavelength regions, opening promising scenarios for spintronics.
OCIS codes: (310.6628) Subwavelength structures, nanostructures, (240.6680) Surface plasmons.

The optical manipulation of magnetic properties in nanostructured materials [1-4] is a very promising research field with several implications in data storage [5], information technology [6] and logical gating [7]. The possibility of finely processing ultrafast magnetic signals opens interesting scenarios in spin-wave manipulation. Recently, in the field of metamaterials, split-ring architectures have been proposed for the excitation of spectrally narrow magnetic resonances in the THz range [8]. However, the geometry of these devices strongly limits the field localization to the size of the ring structure [9].

Here, we present matrices of planar trimer nano-assemblies able to sustain a *coil-type* plasmonic mode in Fano resonance condition. The proposed configuration compensates the ohmic losses with the intense displacement current triggered inside the small interparticle gaps. Furthermore, the plasmonic nature of these resonances induces the sub-wavelength concentration/generation of magnetic hot-spots at optical frequencies [3].

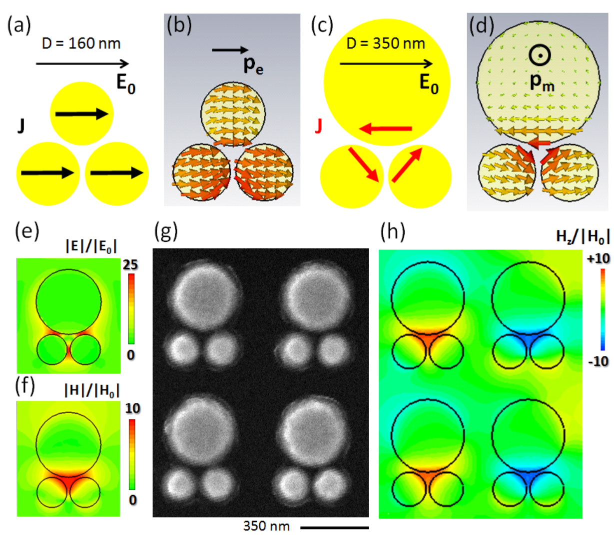

Figure 1. (a) Sketch reporting the D = 160 nm trimer. (b) 2D current density plot of the electric mode sustained by D = 160 nm trimer. (c) Sketch reporting the D = 350 nm trimer. (d) 2D current density plot of the coil-type mode sustained by D = 350 nm trimer. (e,f,h) Respectively electric and magnetic field enhancement distributions in Fano resonance condition. (g) Representative SEM micrograph of the fabricated structures.

Arrays of planar disk trimers supporting close current resonances (see sketch in Figures 1(a-d)) were fabricated on CaF_2 (100) substrates by means of electron beam lithography (EBL) and physical vapor deposition. We fixed the diameter of the lower disks at 160 nm, while the diameter of the upper disk "D" was varied from 160 nm (Figures 1(a,b)) to 350 nm (Figures 1(c-f)). In all cases an interparticle gap of 10 nm was chosen, guaranteeing the strong coupling [10,11] condition inside the trimer (see the electric field enhancement distribution in Figure 1(e)). The spacing among adjacent trimers was fixed at around 150 nm in both x- and y-directions (see representative SEM image in Figure 1(g)). The samples have been characterized via optical transmission spectroscopy in far-field (normal incidence condition), reporting the associated extinction efficiency spectra in Figure 2(b). By exploiting the morphological *symmetry breaking* [3,12] associated to the upper nanodisk, we can promote an intense out-of-phase oscillation of localized surface plasmons (LSPs) inside nanodisk trimers. In this regard, we can compare the charge current density distribution in the case of D = 160 nm (Fig. 1(b)) and D = 350 nm (Fig. 1 (d)). This configuration can induce the hybridization of a dark magnetic mode with a spectrally broad electric mode. In order to separately excite the two modes, we employed two different illumination schemes: i) plane wave impinging normally on the D = 160 nm trimer substrate with polarization parallel to the main axis of the lower disk dimer (electric configuration) and ii) plane wave propagating parallel to the symmetry axis of the D = 350 nm trimer and magnetic field normal to the substrate (magnetic configuration). We plotted in Figure 2(a) the extinction efficiency spectra of the systems in the two cases, obtaining two resonant spectra finely overlapped. In strong coupling condition, the system presents a significant reduction in the extinction efficiency (*i.e.* Fano coil-type resonance in Figure 2(b)) and the resulting current distribution generates an intense magnetic hot-spot within the trimer gap region (Figures 1(f,h)).

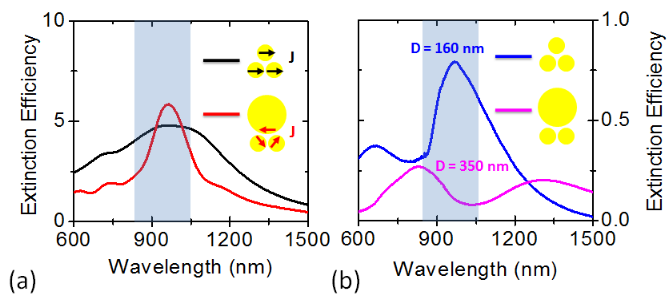

Figure 2. (a) Simulated extinction efficiency spectra for external magnetic field on-plane (black line) and out-of-plane (red line) with respect to the substrate. (b) Measured extinction efficiency spectra of trimer arrays for upper disk diameters equal to 160 nm and 350 nm.

In conclusion, we were able to induce a Fano coil-type resonance in a planar disk trimer nanoassembly for the generation of intense magnetic hot-spots. Applying a morphological symmetry breaking on the system, we could switch from an electric to a coil-type mode by exploiting dephasing effects between the LSPs. Such results are particularly remarkable considering that we conducted our study for exciting radiation orthogonal to the substrate and therefore without external magnetic component aligned to the trimer magnetic moment. Finally, due to the lossless character of Fano coil-type resonances, the proposed device can promote the optical modulation of the local magnetic susceptibility, with straightforward implications in spintronics, superlensing, cloaking, and nonlinear spectroscopy.

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