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Ultrathin Quadrifilar Spirals and Spiral Ensembles

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***Abstract* – We investigate the eigenmodes of both ultrathin quadrifilar spirals and ensembles made up of such spirals by comparing experimental near-field scans with numerical finite-element models. These modes can be understood in the picture of electric and magnetic localized spoof plasmons.**

I. INTRODUCTION

The effective properties of most metamaterials in the optical regime rely on the plasmonic properties of the elements they are made up of. At lower frequencies, however, metals can be regarded as perfect conductors and do not support surface plasmons. Yet, comparable excitations can be mimicked by structuring the metal surface [1], [2] or the surface of a metallic object to achieve the analogue of the localized plasmons [3] that are utilised in metamaterial building blocks. These localized spoof plasmons have recently been shown to have magnetic resonances alongside electric ones [4].

We investigate these magnetic and electric components of localized spoof plasmon modes for ultrathin quadrifilar copper spirals and ensembles built from small numbers of such spiral elements. The samples are fabricated from a 18µm copper film on top of a 50µm mylar substrate by an etch-mask technique and the electric fields around the resulting structures are mapped with a microwave near-field scanner. These electric field data are compared to finite-element models, which help us interpret and extend our experimental findings.

II. EIGENMODES OF QUADRIFILAR SPIRALS

First, we study the electric and magnetic resonances of an individual ultrathin quadrifilar spiral with a radius R=7.2mm and w=0.25mm wide arms in comparison with its complementary structure, a spiral-shaped aperture in an 18µm copper sheath on top of a 50µm mylar substrate. Our near-field scans – presented in Fig. 1 (a) and (b) – reveal three resonances within the considered frequency range: an electric dipole resonance at 2.95 (2.85) GHz, a magnetic dipole resonance at 4.95 GHz and an electric quadrupole resonance at 8.50 GHz.

The experimental field maps, which are dominated by the out-of-plane electric field, agree well with the numerical calculations for the z components of the electric and magnetic field (Fig 1 (c) and (d) respectively). To be precise, the fields measured on the copper spiral show the same spatial pattern as the modelled E_z in a cut plane 0.5mm above the metal surface, whereas the fields found on the complementary spiral are reproduced by the modelled magnetic field H_z of the direct structure, only with the sign switched. This is in agreement with Babinet's principle [5], which relates the electric field of a thin metal structure with the negative magnetic field of its complementary structure ($E = - B$).

Having thus examined the properties of the localized spoof plasmons supported by individual quadrifilar spirals, we use to build small ensembles from several elements and investigate the modes of the coupled systems and how these are influenced by the arrangement of the individual spirals within the ensemble and by the position of the source used to excite the structure.

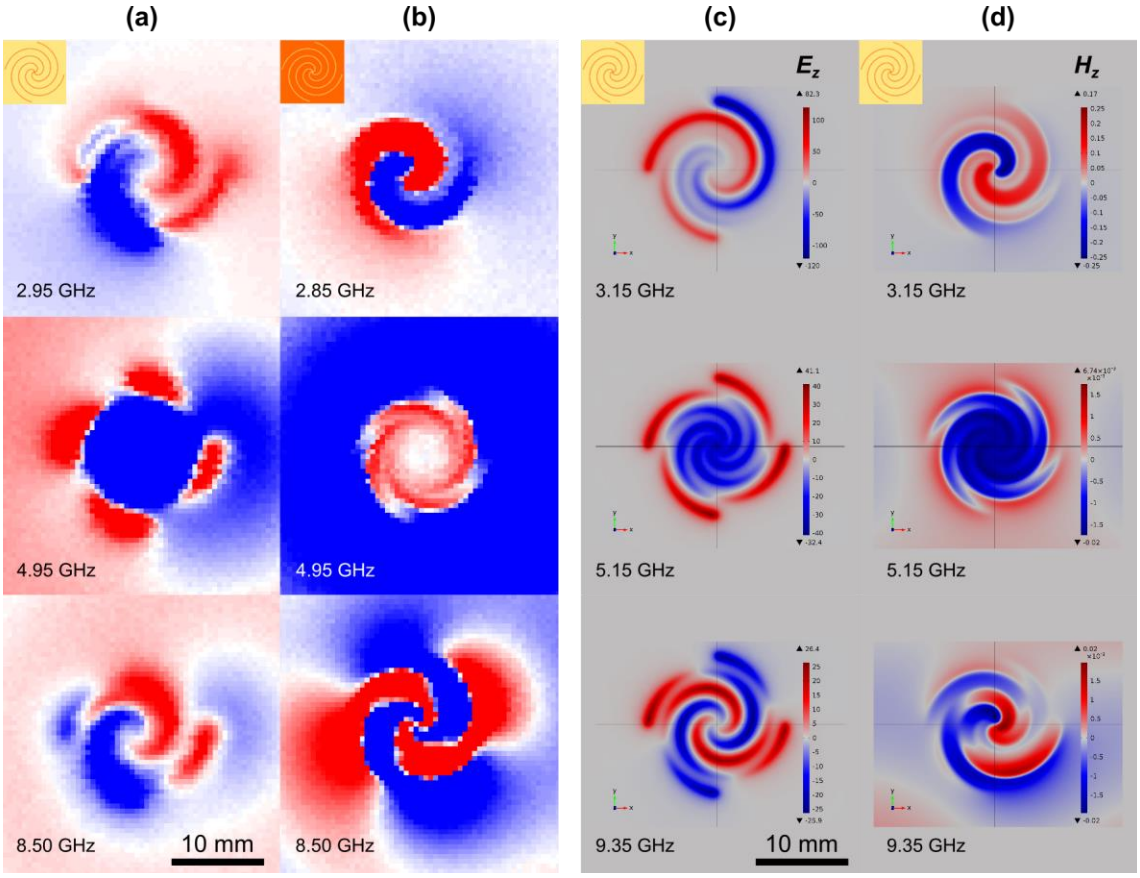

Fig. 1. Comparison of measured (a and b) and calculated (c and d) field maps for individual quadrifilar spirals (R=7.2mm w=0.25mm, t_m=18µm) of the direct copper spiral (a) and its complementary structure, a spiral aperture in a thin metal film (b). The measurements are dominated by the out-of-plane component of the electric field (E_z). Columns (c) and (d) show finite-element models of the out-of-plane component of the electric (E_z) and magnetic (H_z) field evaluated 0.5mm above the direct metal structure.

IV. Conclusion

Individual copper spirals support both electric and magnetic localized spoof plasmon modes which can be utilized to build spiral ensembles and control the resulting coupled response in various ways, allowing for antenna systems with diverse properties.

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