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Electromagnetic Coupling Mechanisms in Vertically Oriented Metallic Plasmonic Inclusions

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***Abstract*—Structured electromagnetic materials have experienced a renaissance with the emergence of metamaterial and plasmonic research. The ability to orient metallic plasmonic inclusions vertically enables orientation-dependent coupling arrangements which cannot be achieved in conventional planar engineered materials. In this paper we discuss these coupling arrangements and their effect on the measured far field scattering response to normally incident excitation.**

***Keywords*—plasmonics; metamaterials; 3-Dimensional**

I. Introduction

The vast majority of published research into micrometer-scale metamaterial and plasmonic structures focuses on planar and stacked planar structures, necessitated by fabrication methods which exhaust all of their flexibility creating structures with the requisite dimensions, with no room left for orienting the structures out of plane. A few methods have emerged which are capable of creating micron-scale structures with out of plane elements [1-6]. Fig. 1 shows a schematic of the kinds of coupling enabled by fabrication of vertically oriented structures. Planar structures can employ lateral in-plane coupling, and, through layer-by-layer fabrication, achieve a stacked planar coupling for out of plane coupling. This stacked-planar coupling is responsible for some of the most successful micron-scale metamaterials such as the fishnet and cut-wire pair structures.

Vertically oriented geometries can achieve in-plane lateral coupling as well as back-to-back coupling of vertical structures, and coupling on orthogonal vertical planes. Combining these degrees of freedom with a layer-by-layer approach enables the full complement of 3D coupling arrangements.

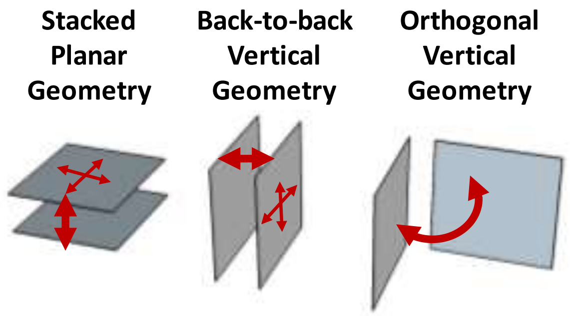

Fig. 1 Schematic depiction of coupling arrangements for planar and vertically oriented inclusions.

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II. Fabrication

Using membrane projection lithography, dense 2-D arrays of micron-scale, cubic unit cells with 1-inclusion and 2-inclusion bases were fabricated in silicon following the approach schematically shown for a single unit cell in Fig. 2. Cavities are formed (Fig. 2a), backfilled with silicon dioxide and planarized using chemical mechanical polishing (Fig. 2b). An aluminum nitride membrane is deposited and patterned (Fig. 2c) allowing hydrofluoric acid removal of the backfill oxide (Fig. 2d). Directional evaporations (Fig. 2e, 2f) decorate the interior of the cavity with metallic replicas of the pattern. Liftoff of the AlN membrane yields the final 2-dimensional array of decorated unit cells. These structures are created on 150 mm silicon wafers on a 150 mm CMOS fabrication line using 248 nm lithography. The samples are 1 cm^2, and except for rare defects, are uniform over the entire patterned area.

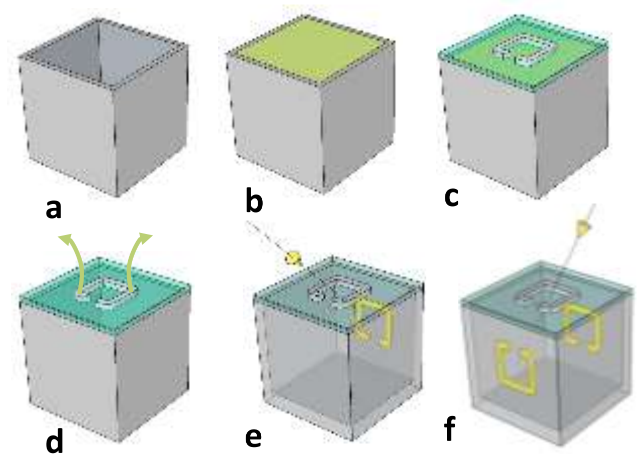

Fig. 2 Schematic depiction of the membrane projection lithography processing sequence.

Fig. 3 contains SEM micrographs of two examples of these structures. In Fig. 3a, the consecutive evaporations were performed with a 180-degree rotation between evaporations such that back-to-back split ring resonators result. In Fig. 3b, a

90-degree rotation was used so that resonators placed on orthogonal walls result.

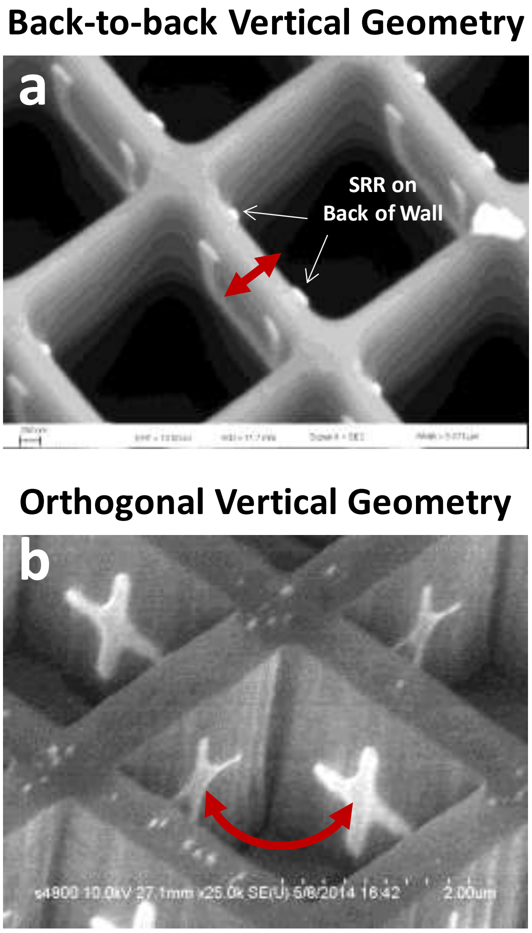

Fig. 3 SEM images showing (a) Split ring resonators in a back-to-back vertical configuration; (b) Cross dipole resonators in an orthogonal vertical configuration.

III. Discussion

The scattering response of these structures is highly polarization dependent. For 1-inclusion unit cell arrays, the in-plane orientation of incident linearly polarized light affects the coupling to meta-atoms oriented on vertical sidewalls. For linear polarizations aligned parallel to the wall containing the inclusions, a resonant excitation of the meta-atom results, dramatically changing the far-field scattering response. For light linearly polarized orthogonal to the plane containing the meta-atoms, the scattering response is virtually indistinguishable from that of an undecorated silicon array.

For meta-films with a 2-inclusion basis inside the unit cell (both back-to-back and orthogonally oriented versions), changes in the far-field scattering response are apparent relative to the single inclusion case.

This paper will present infrared optical characterization data demonstrating the ability to modify the far-field scattering response by altering the unit cell meta-atoms, their orientation and number of inclusions in the basis.

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