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Fabrication of Artificially Structured Materials Using Membrane Projection Lithography

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Abstract: We present membrane projection lithography as a method to create arrays of 3-D unit cells decorated with metallic inclusions. Fabricated resonators possess out-of-plane current flow and micron scale dimensions with ~10 um resonance wavelength.

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1. Introduction

For a material with engineered inclusions to perform as a true bulk material, the inclusions must be both small relative to the design wavelength, and possess 3D structure capable of supporting isotropic response to incident electromagnetic fields, competing requirements which challenge most current fabrication techniques. We present three versions of membrane projection lithography (MPL) as a fabrication technique capable of generating artificially structured materials with designed inclusions with isotropic, 3D electromagnetic elements in the metamaterial size limit. All three approaches entail shadow evaporation of the designed inclusion through a patterned membrane onto an underlying cavity, however, each approach has a varying degree of process complexity and final electromagnetic performance. Following the solid state analogy, the result of MPL in all its variations is creation of a lattice of unit cells with a basis consisting of instances of the designed inclusions.

2. Fabrication

The most general form of MPL entails creation of a cavity, backfill and planarization, membrane deposition and patterning, backfill removal and directional evaporation through the patterned membrane. Because the cavity and membrane pattern are formed independently, this approach is capable of creating independently optimized unit cell geometry, lattice geometry, and unit cell decoration or basis patterning at the expense of process complexity. Fig1a. contains a schematic diagram of the membrane suspended over the cavity prior to evaporation in the top figure and an SEM image of a 3D cubic structure created using this approach. The inset SEM image shows a portion of the 5mm x 5mm square 2-D array fabricated. The sample was uniform over this entire area.

In some cases, it may be possible to relax the requirements on the unit-cell geometry, such that a spheroidal cavity will suffice. In this case, Self-Aligned Membrane Projection Lithography (SAMPL) can be used. SAMPL begins with deposition of the membrane material directly on a substrate with an isotropic dissolution mechanism (for instance an HF etch of a silicon dioxide layer). The membrane is patterned and the pattern used to introduce the substrate dissolution chemistry, forming a self-aligned spheroidal cavity immediately beneath the patterned membrane. Direction evaporation and lift-off then complete the process flow. Figure 1b. shows a spheroidal decorated with split ring resonators created using SAMPL. The inset shows a uniform 2-D array.

Finally, if the constraints on the unit-cell geometry can be further relaxed, Single-Evaporation Membrane Projection Lithography (SEMPL) can be used. SEMPL also begins with deposition of the membrane material directly on a substrate with an isotropic dissolution mechanism, but in this case the entire suite of unit cell decorations are created in the membrane. This larger membrane pattern results in a less isotropic cavity than SAMPL, but only a single normally incident evaporation is required to deposit the unit-cell decorations. Fig 1c. shows the schematic and resulting SEM of the SEMPL process flow. In this case, a small square feature was added to the membrane pattern to ensure the cavities under each resonator joined to form the final clover-shaped unit cell cavity. Again, the inset shows a 2-D array of these unit cells, uniform over the entire 5mm x 5mm sample.

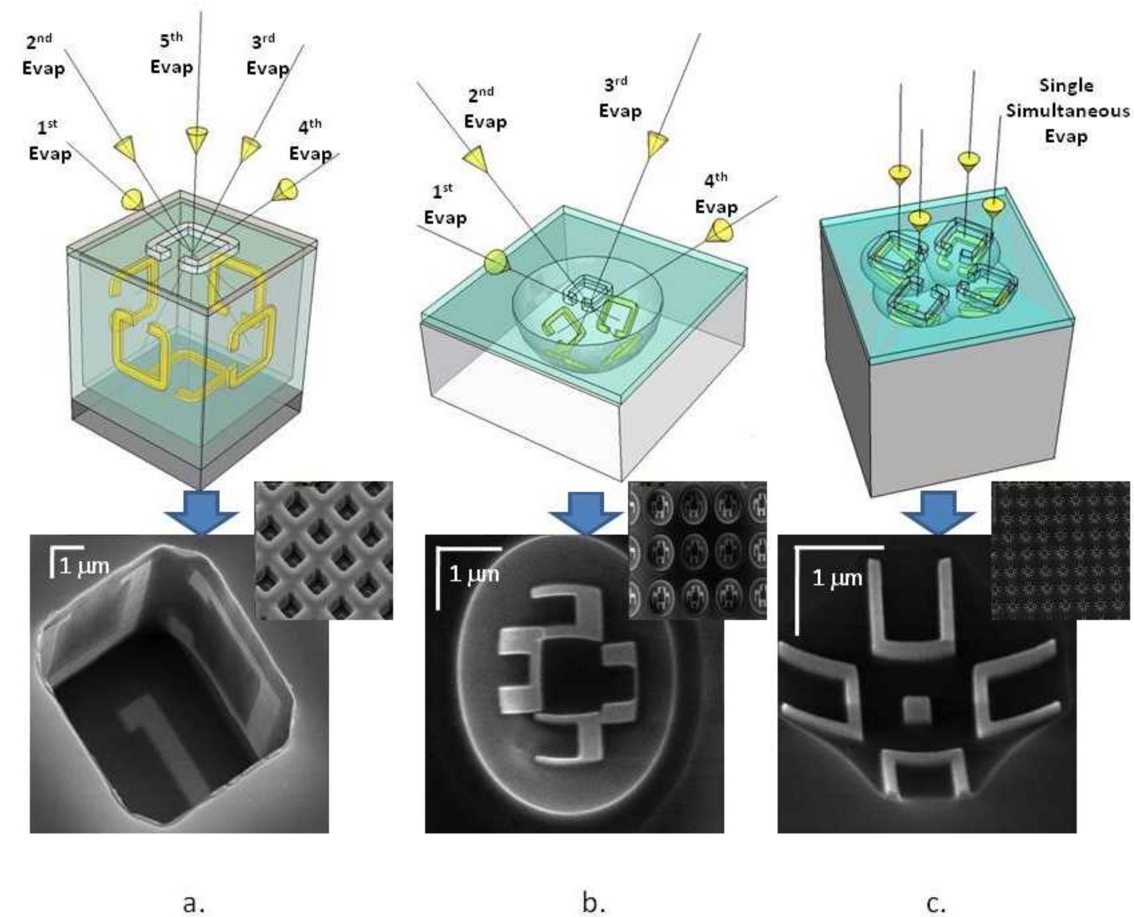

Figure 1. Schematic drawings and SEM images of split ring resonator decorated cavities generated through a.) Membrane Projection Lithography (MPL), b.) Self-Aligned Membrane Projection Lithography (SAMPL) and c.) Single Evaporation Membrane Projection Lithography (SEMPL).

3. Conclusion

MPL is a versatile fabrication technique capable of creating micron scale unit-cells decorated with micron/sub-micron scale patterns. Split ring resonators were used in this work as a template pattern. Obviously the approach is relatively independent of the choice of resonator pattern. These structures all possess out of plane current flow, and exhibit measured electromagnetic response indicating the out-of-plane nature of these resonators. We will present transmission FTIR and hemispherical directed reflectivity data showing clear resonance behavior, and deviation from planar control samples. Future work includes exploration of the role of pattern and projection symmetry on electromagnetic performance, and continual work to push the resulting resonator size scales to smaller dimensions.

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