Fabrication Techniques for 3D Metamaterials in the Mid-infrared

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Since the first demonstration of simultaneous negative values of effective permeability and permittivity in a 3D metamaterial at microwave frequencies,[1] there have been efforts to replicate such a structure at optical frequencies. But creating isotropic 3D structures at dimensions three orders of magnitude smaller than those required for microwave frequencies presents significant fabrication challenges. We have developed two versions of a flexible fabrication technique known as Membrane Projection Lithography (MPL) that can produce nearly arbitrary patterns in "2 ½ D" and fully 3D structures in the mid-infrared.

The first version is known as Self-Aligned Membrane Projection Lithography (SAMPL) because the resulting patterns are self-aligned to a spheroidal bowl formed through the membrane. Fig. 1(a) shows a membrane of patterned PMMA over a shallow bowl in polyimide. Fig. 1(b) shows a set of split ring resonators (SRR) in gold after normal evaporation and liftoff. We informally refer to this as "2 ½ D" because while no longer planar, the patterns are only about 20 degrees out of the plane.

The second version is a slightly more complicated process consisting of two main steps. First, using standard optical lithography, a 2D grid of open boxes is formed in SU-8 and then planarized with polyimide. Second, PMMA is spun on and patterns are exposed aligned to the underlying boxes. Fig. 2(a) shows the patterned PMMA membrane that acts as a stencil for multiple angled evaporations after the polyimide has been dissolved out of the boxes. Fig. 2(b) shows a fully 3D structure after five evaporations have placed a set of four SRRs on each of the five surfaces.

Both of these techniques utilize e-beam lithography to achieve the required submicron feature sizes, to allow for multiple designs and rapid design changes, and for precision alignment in the second version. While we developed these processes using PMMA, polyimide, and SU-8, the choice of materials for membrane, bowl, and box is quite flexible. And it may also be noted that these techniques may be performed serially to create stacked versions with multiple periods in the vertical direction.

We will show some of the many variations of these techniques and show how the infrared reflection and absorption spectra change compared to planar structures.

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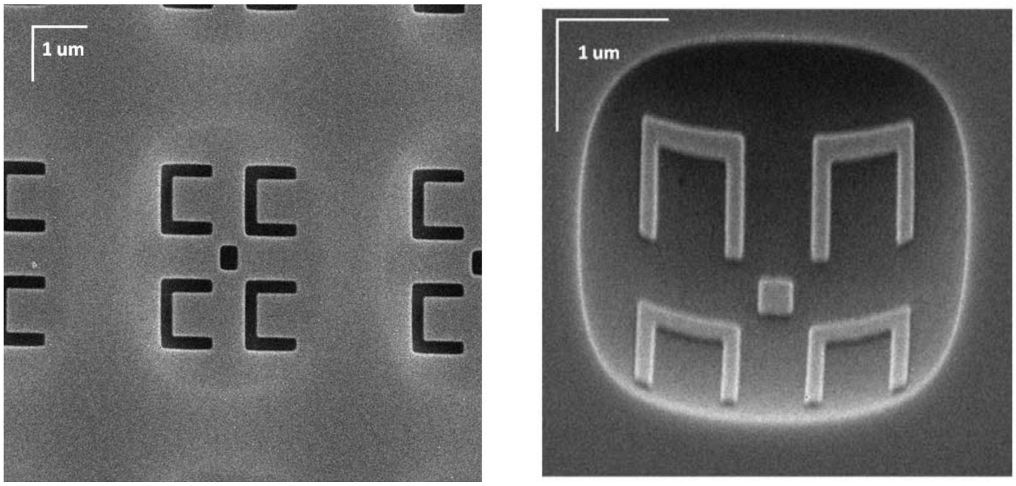
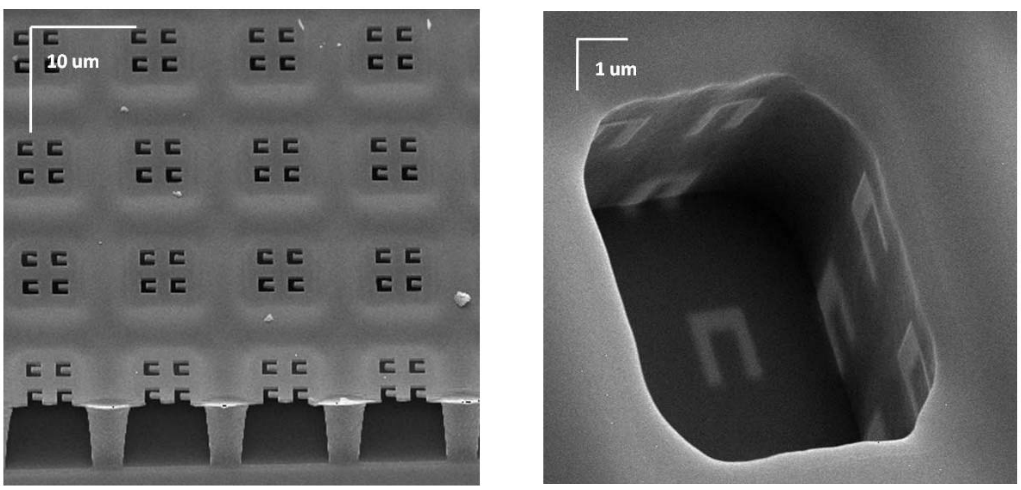
[1]D. R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, Phys. Rev. Lett. 84, 4184 (2000).



(a) **(b)**

Fig. 1. (a) Scanning electron micrograph of a patterned PMMA membrane suspended over a bowl formed in polyimide. (b) Scanning electron micrograph of gold SRR patterns deposited into the bowl after liftoff. Patterns are approximately 20 degrees out of plane.



(a) **(b)**

Fig. 2. (a) Scanning electron micrograph of a patterned PMMA membrane suspended over and aligned to boxes formed in SU-8. (b) Scanning electron micrograph of gold SRR patterns deposited onto the five box surfaces after liftoff (only three surfaces visible).