

Metamaterial Structure Fabrication Using DPN

Rev: 01.0611

Introduction

Metamaterials are artificially engineered structures that have properties unusual properties that may not be found in naturally occurring materials.¹ The engineered structure, rather than the material composition is the basis for these unusual properties. The primary research topic in metamaterials is the negative refractive index behavior of metamaterials. The negative refractive index can be obtained by correlation between sub-wavelength structures in metamaterials and electromagnetic waves. Using this negative refractive index behavior, several research applications have been tried, including photonic metamaterials, superlens, cloaking devices, acoustic metamaterials, and metamaterial antennas.²

Split-ring resonator (SRR) structures comprise the most common examples of negative index metamaterials (NIMs). SRR structures have been studied for potential use in Terahertz (THz) and acoustic metamaterials, as well as in metamaterial antennas.^{2,3}

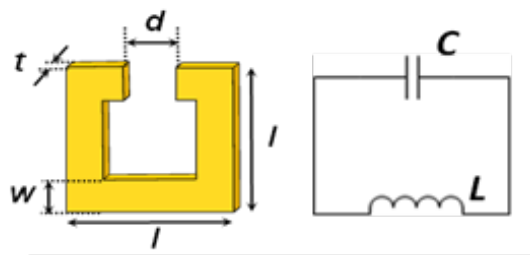


Figure 1. Illustrations comparing split-ring resonators (left) and conventional LC oscillators (right).

Figure 1 compares a SRR to a conventional LC oscillator. The resonance frequency of an LC oscillator (ω_{LC}) is determined by the inductance (L) and capacitance (C) of the circuit in the relationship $\omega_{LC} = (LC)^{-1/2}$. In SRRs, L and C are dependent on SRR dimension, so SRR resonance frequency can be controlled by manipulating its geometrical parameters. SRR structures fabricated to sub-micron dimensions generate electromagnetic responses in the THz range, which is close to the spectrum of visible light.

E-beam lithography is the methodology most commonly used to fabricate nanoscale SRRs. While e-beam lithography does enable high resolution SRR fabrication, practical applications of this platform are limited because of the high costs and scale-up difficulties involved with e-beam lithography. Here we demonstrate a highly scalable, tip-based method of fabricating split-ring resonators that overcomes the

difficulties encountered with e-beam lithography.

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Top-Down Nanofabrication by DPN

Dip Pen Nanolithography® (DPN®) is an established method of nanofabrication in which materials are deposited onto a surface using a sharp tip. DPN can be used to fabricate features with diameters as small as 50 nm using small molecules such as alkanethiols. DPN-deposited alkanethiol patterns can be used as etch resists for top-down nanofabrication processes⁴.

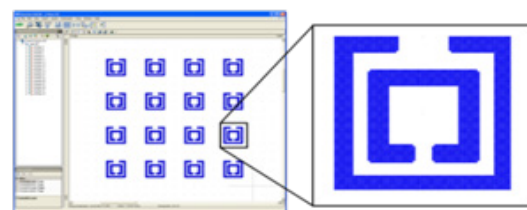


Figure 2. DPN pattern for SRR array design (left). An array of 3057 dots was used for individual SRR design. Ring widths and distances between outer and inner rings are 400 nm. Gaps in outer and inner rings are 1.2 μm and 400 nm, respectively.

In addition to generating small feature sizes, NanoInk's powerful DPN 5000 System enables rapid and flexible design of feature geometry. Just as importantly, the DPN 5000 System fabrication process can be scaled up to pattern several hundred to over several thousands of features in relatively short periods of time by using a NanoInk custom designed 1D or 2D multiple-tip cantilever "pen" array.⁵ These features make DPN an efficient and cost effective method for fabricating nanoscale SRRs.

Fabricating Split-Ring Resonators

An array of DPN-fabricated SRR structures was constructed by incorporating three different double-ring SRR designs (circle-square, circle-circle, and square-square). This nanoarray was created using a NanoInk 1D 26-"pen" array (DPN Pen Array: Type

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(continued)

F) to pattern 16-mercaptohexadecanoic acid (MHA) on a 10 nm thick gold film with a 2 nm of Titanium adhesion layer, on a silicon oxide substrate. The MHA to pattern 16-mercaptohexadecanoic acid (MHA) on a 10 nm thick gold film with a 2 nm of Titanium adhesion layer, on a silicon oxide substrate. The MHA patterns were utilized as a resist to etch the gold surface. Figure 3 shows an SEM image of the resulting SRR array structures, as well as high resolution SEM images and AFM images of the three different types of nanoscale SRRs.

In total, this experiment generated 1248 SRRs, 416 each of the three different double-ring SRR designs, using a top-down DPN fabrication approach.

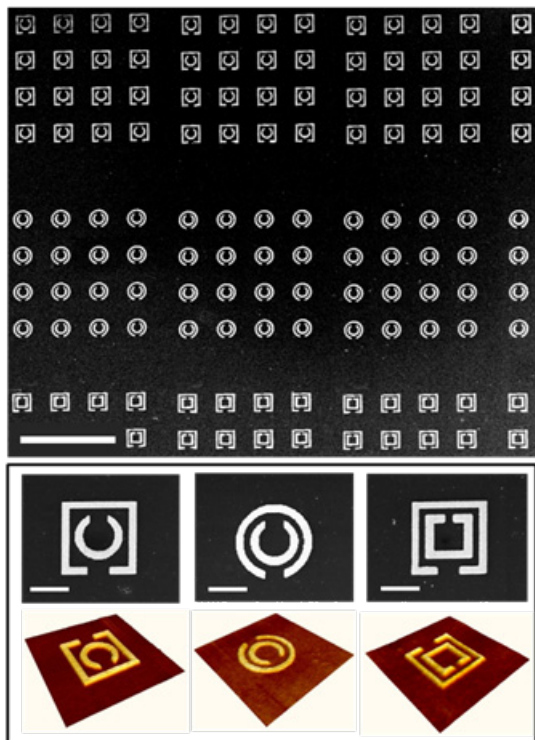


Figure 3. SEM image of DPN-fabricated SRR array (top), with scale bar of 20 μm . Highly magnified SEM images (middle) and 3-D AFM topographic images (bottom) of individual SRR circle-square, circle-circle, and square-square structures (left to right) fabricated without defect, with scale bars of 2 μm .

Conclusion

We have successfully fabricated nanoscale SRR arrays using the NanoInk DPN 5000 System. Results demonstrate that parallel DPN methodologies are

capable of quickly and easily scaling up fabrication of SRR metal structures, making DPN an enabling technology for future studies of negative index metamaterials.

References

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NanoInk Products Used

DPN 5000 System
 DPN® Pen Arrays: Type F
 DPN® Substrates: Gold

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