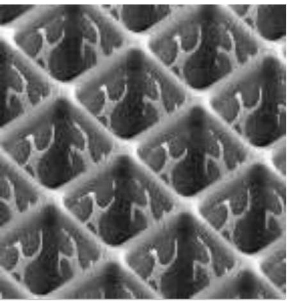
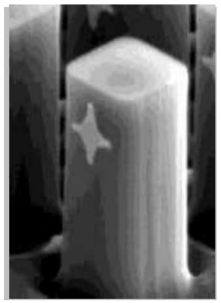
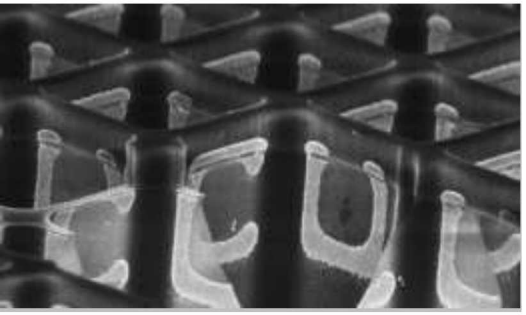

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SAND2020-2198C

Unique Properties of 3D Infrared Metamaterials

August 23, 2018

Bruce Burckel

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U.S. DEPARTMENT OF ENERGY

NNSA

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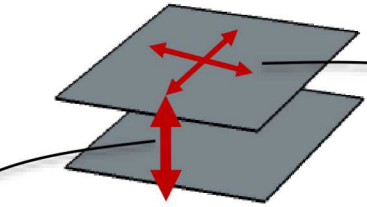
Outline

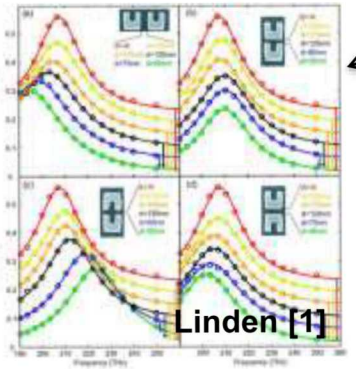
1. 3D Metamaterial Atoms – unique coupling and scattering response
2. MPL Fabrication – 3D meta-films
3. Unique behaviors for 3D meta-atoms

Comparing Coupling Mechanisms in Planar and Vertical Structures

Sandia National Laboratories

Stacked Planar Geometry

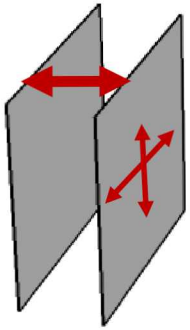


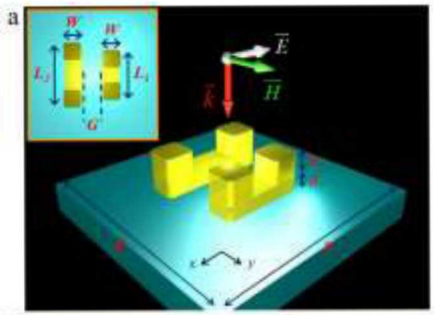


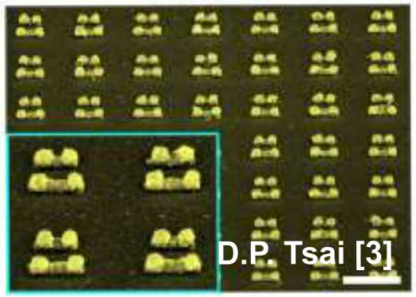
Linden [1]

Giessen [2]

Back-to-back Vertical Geometry

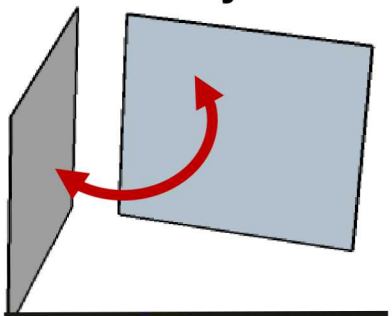


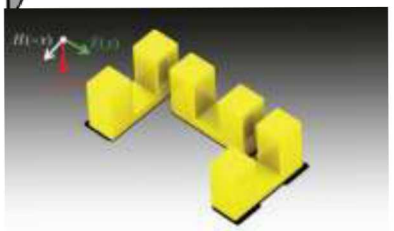


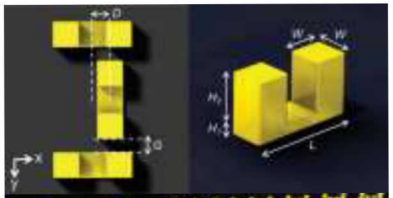


D.P. Tsai [3]

Orthogonal Vertical Geometry



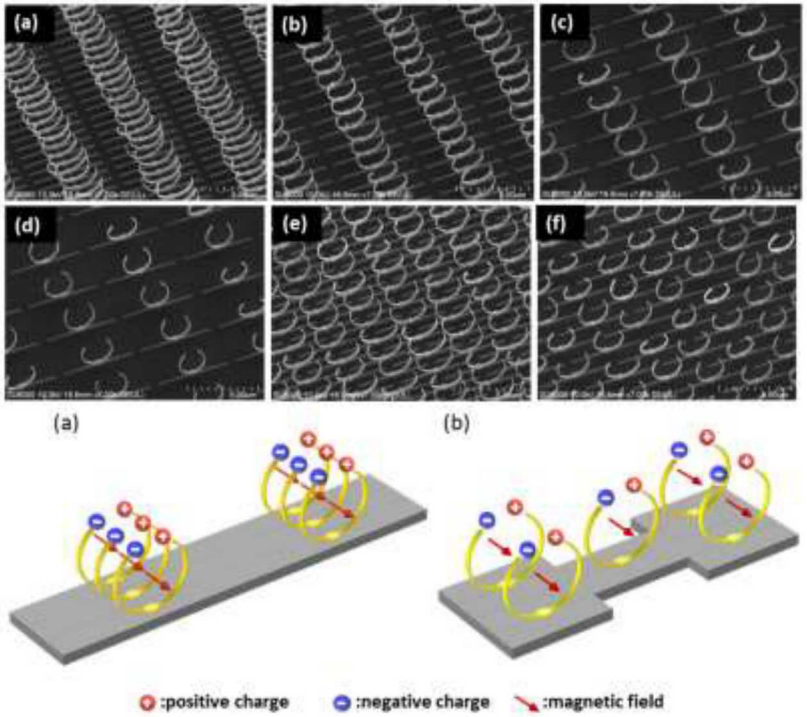




D.P. Tsai [4]

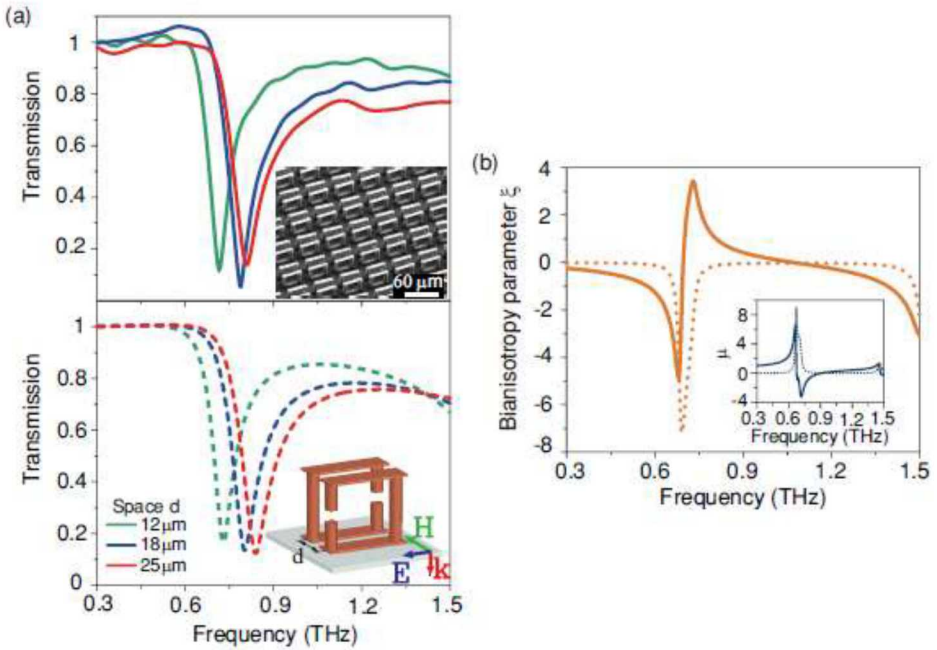
Unique Coupling Mechanisms in Vertical Structures

Horizontally Oriented Magnetic Dipole



Tanaka and Chen [5]

Unambiguous Coupling to Normally Incident Magnetic Field

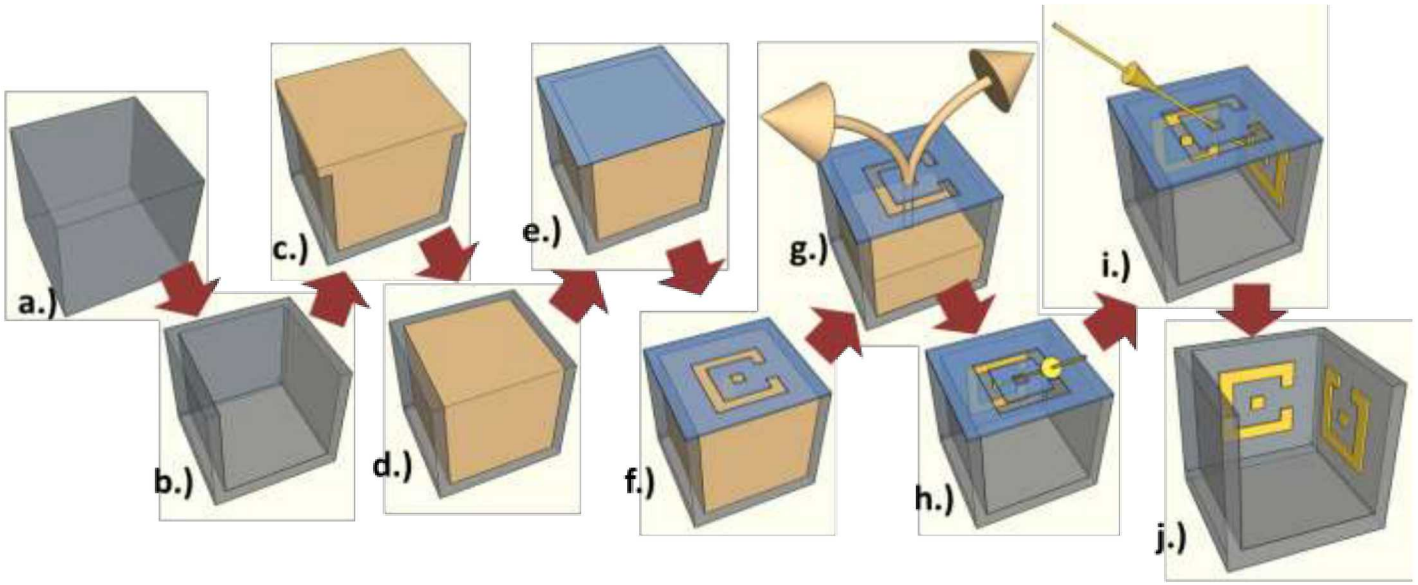


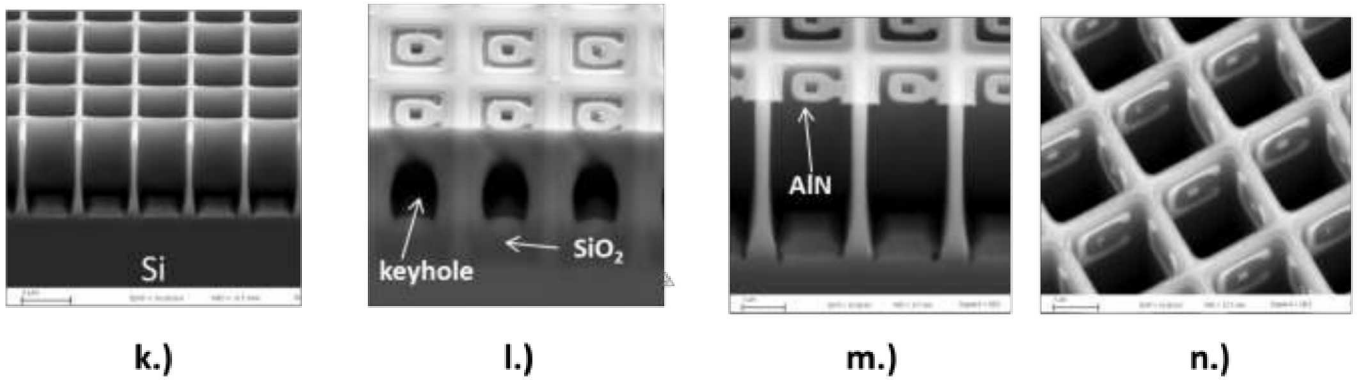
Averitt [6]

Membrane Projection Lithography (MPL)

3D Micron-scale Fabrication Approach

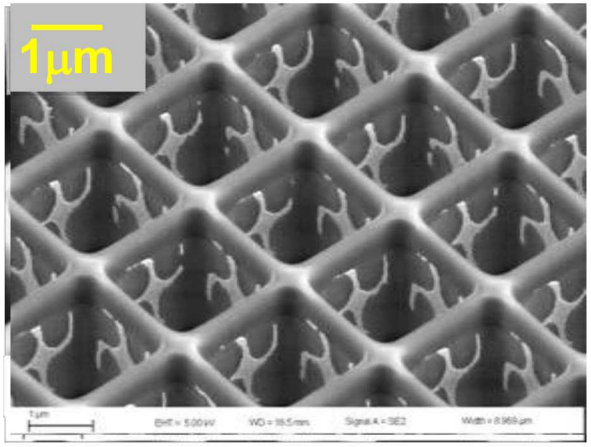
Membrane Projection Lithography

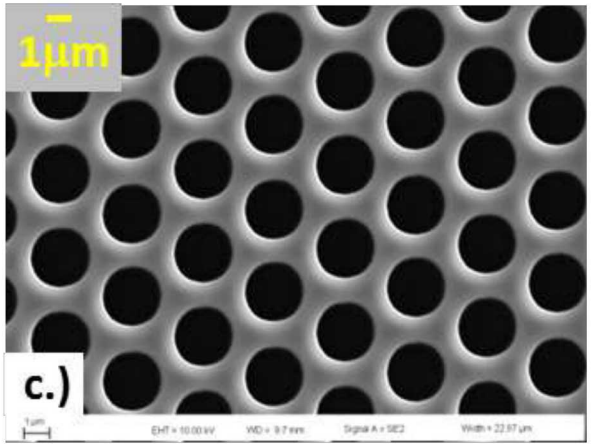


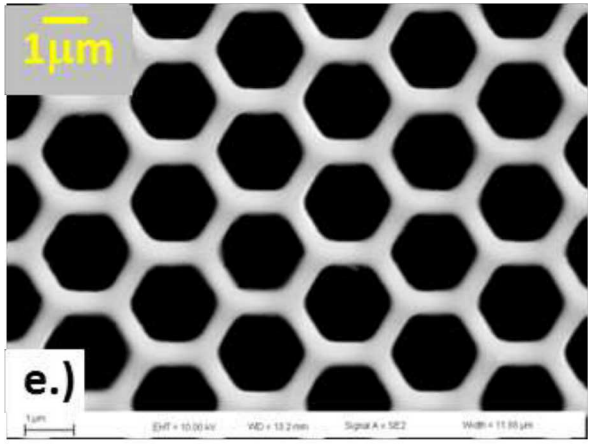


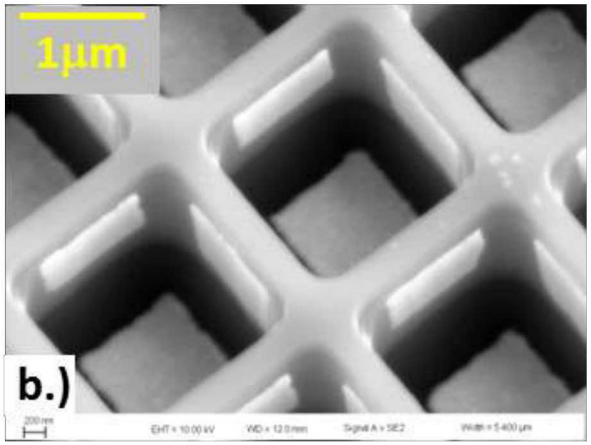
D. Bruce Burckel, Paul J. Resnick, Patrick S. Finnegan, , Michael B. Sinclair and Paul S. Davids "Micrometer-scale fabrication of complex three dimensional lattice+basis structures in silicon," Optical Materials Express, , 5, 2231-2239, (2015).

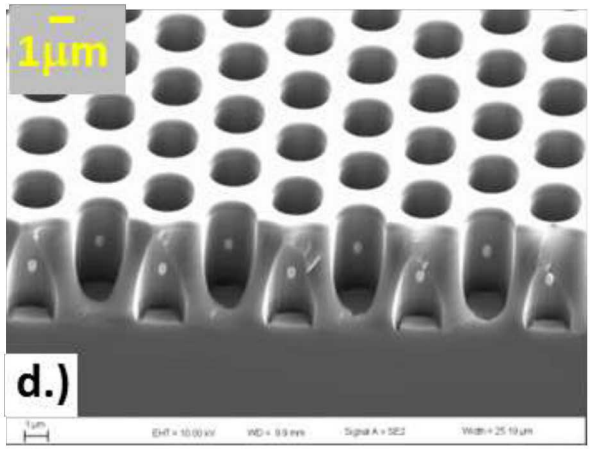
3D micron-scale Metamaterials

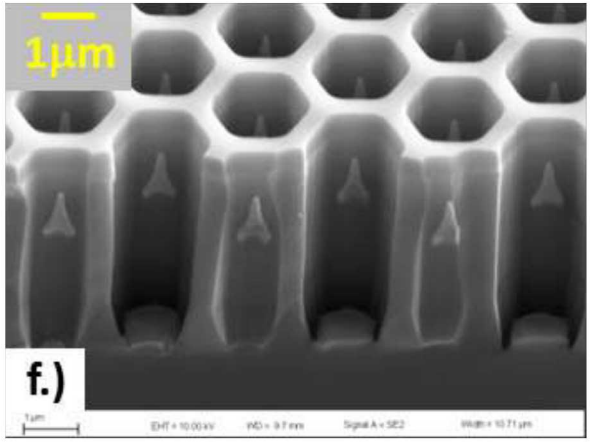




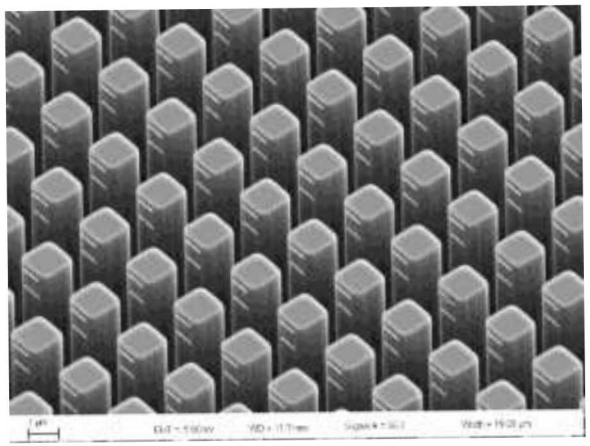
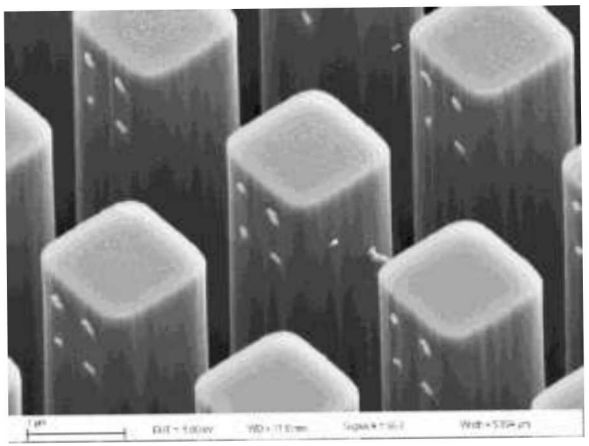
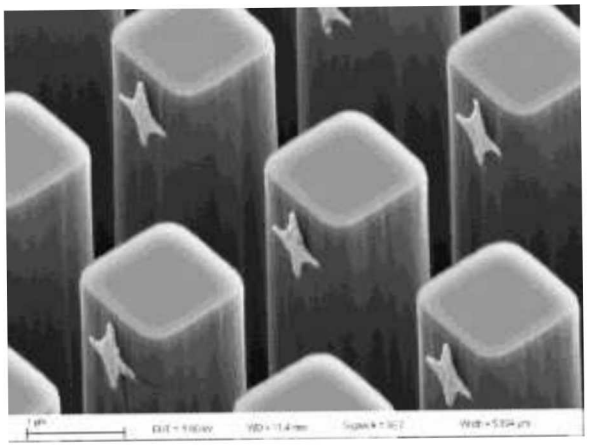
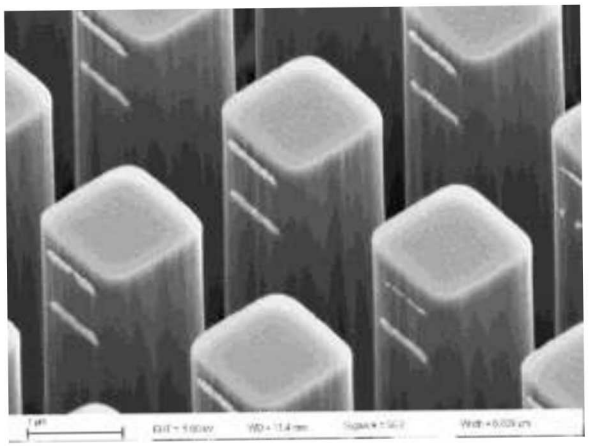
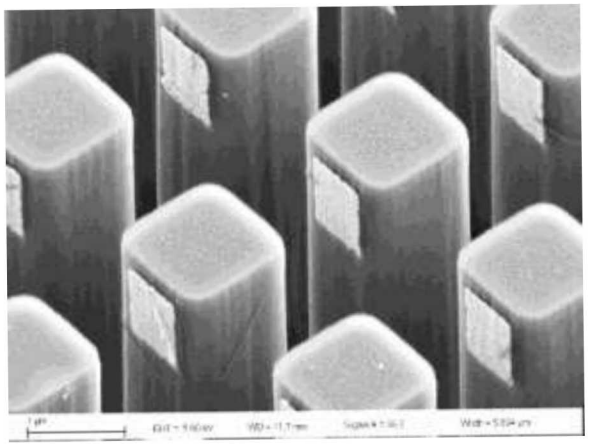
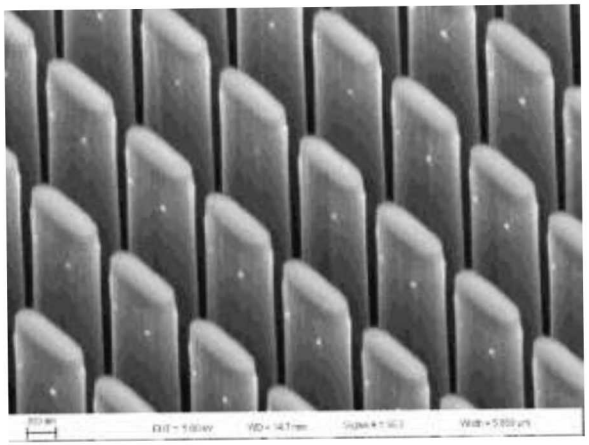




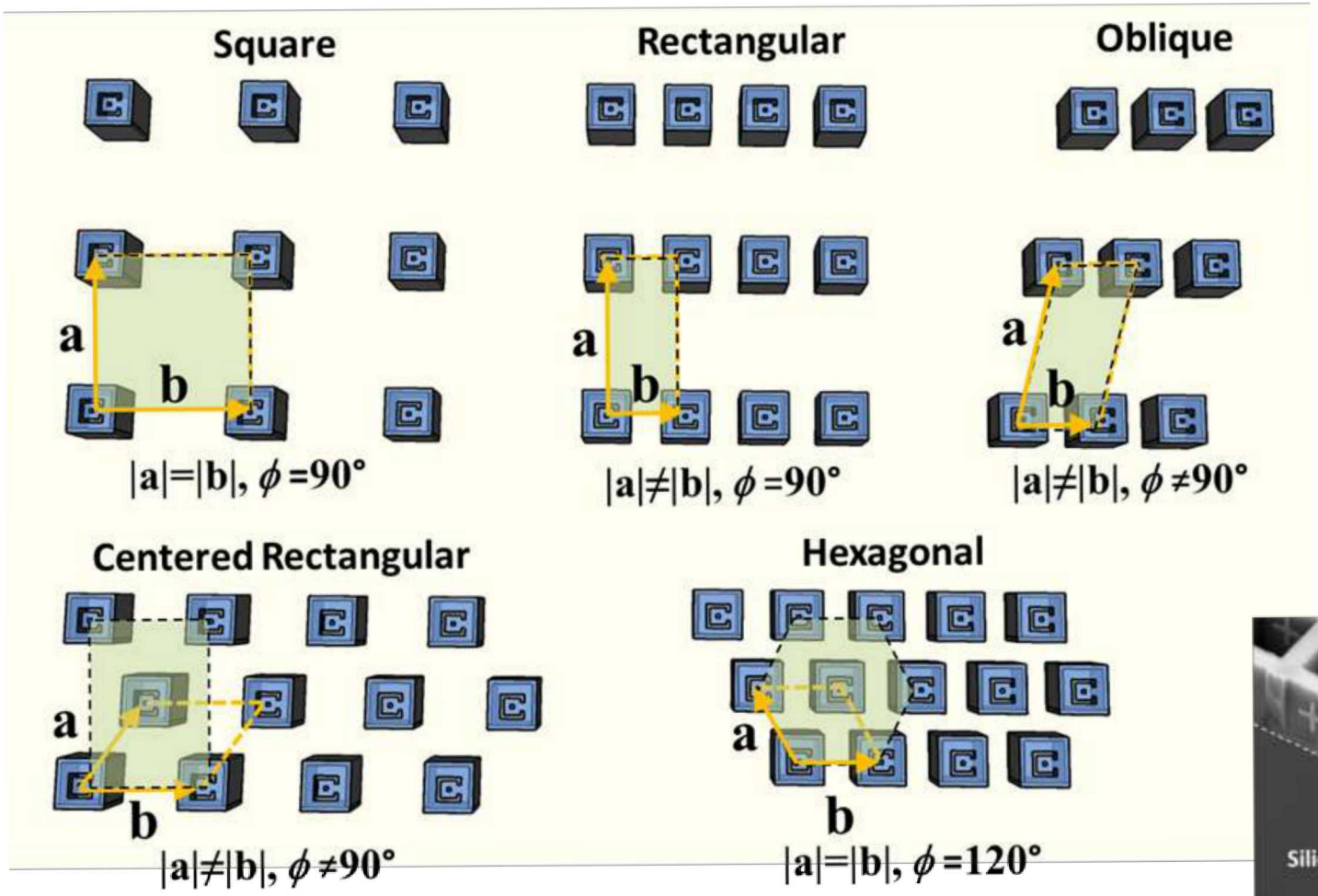


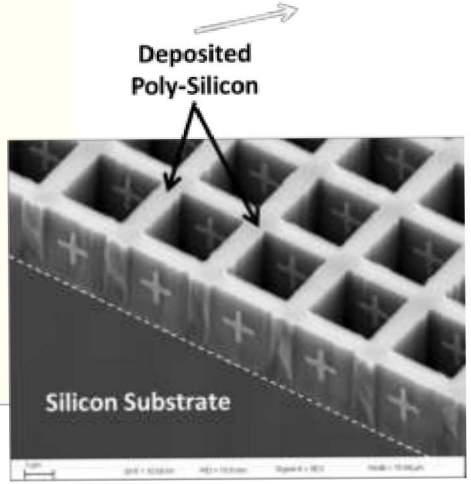


3D micron-scale Artificial Dielectrics

2-D Lattice + Basis

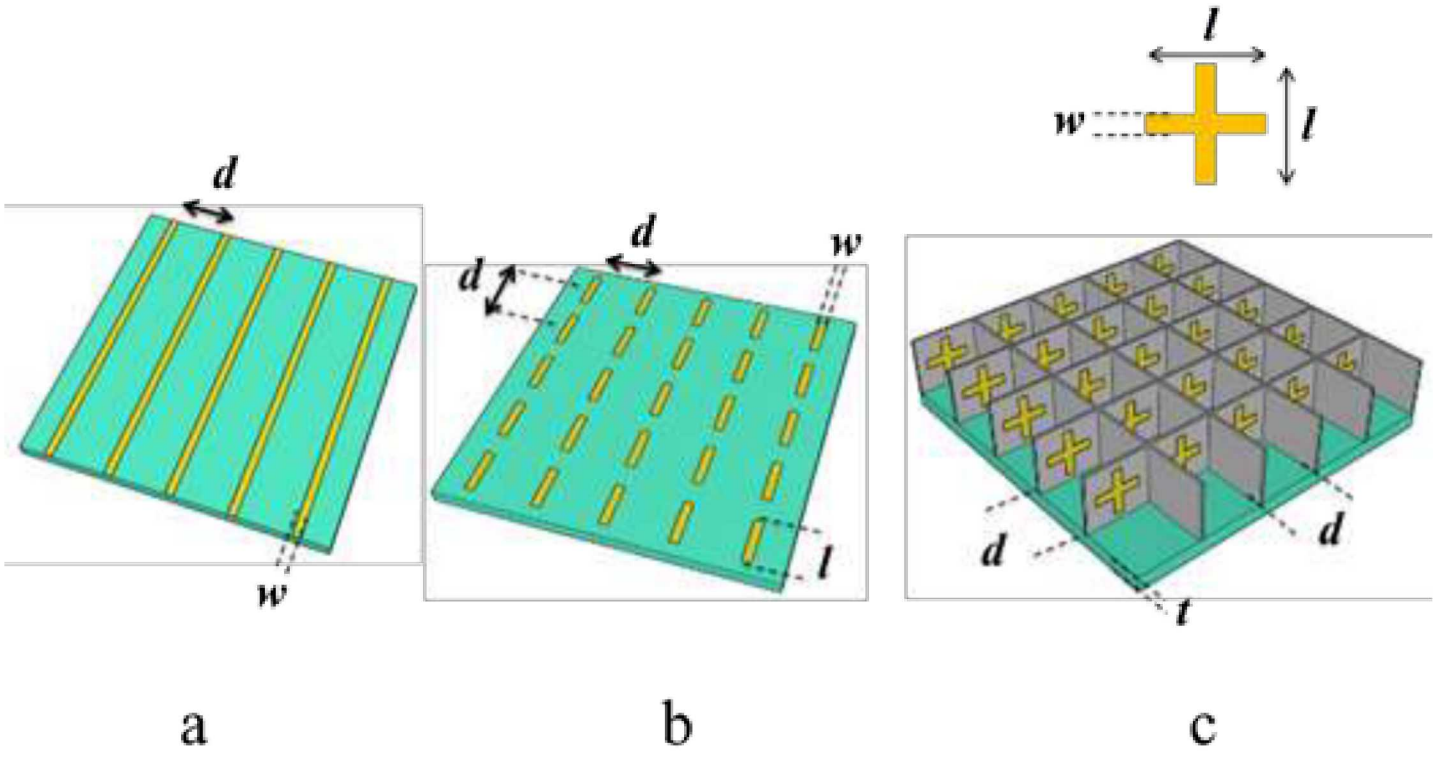




Path to all 14 3D Bravais Lattices?

Vertical Back-To-Back Wire Grid Polarizers

Planar and Vertical Wire Grid Polarizer Geometries



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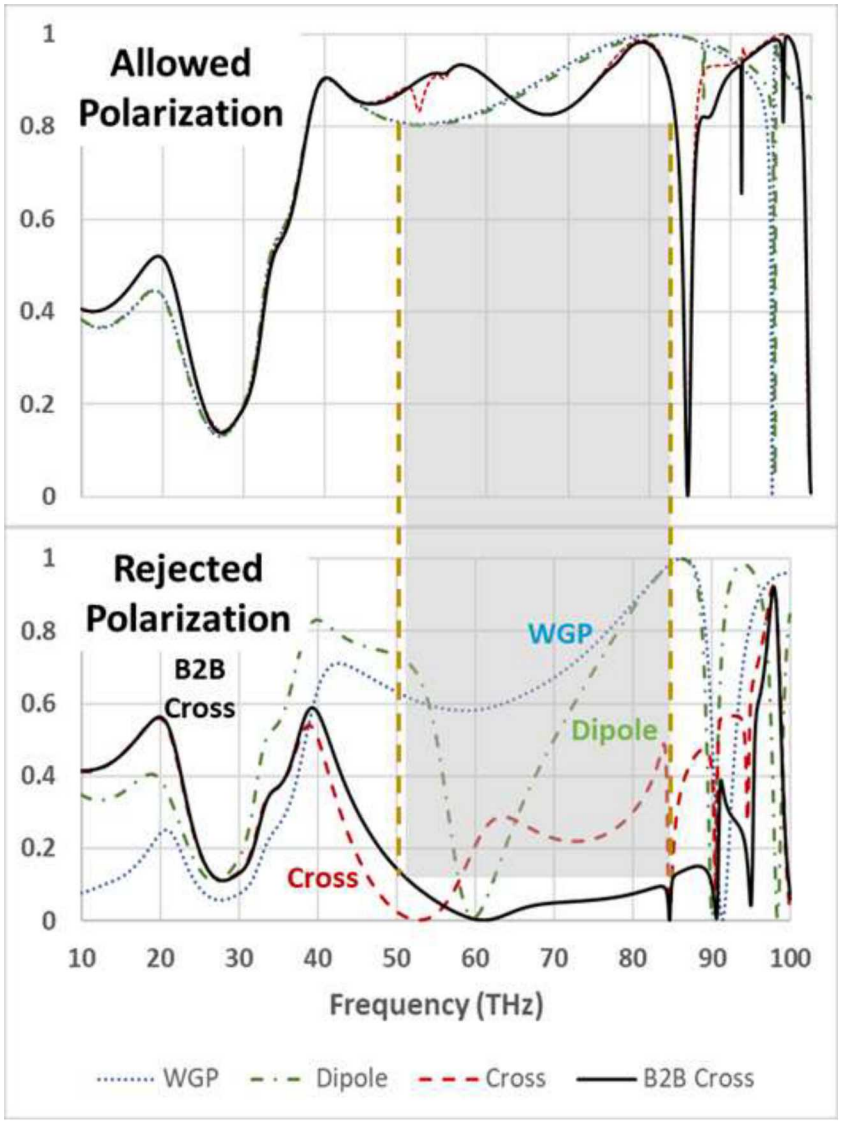
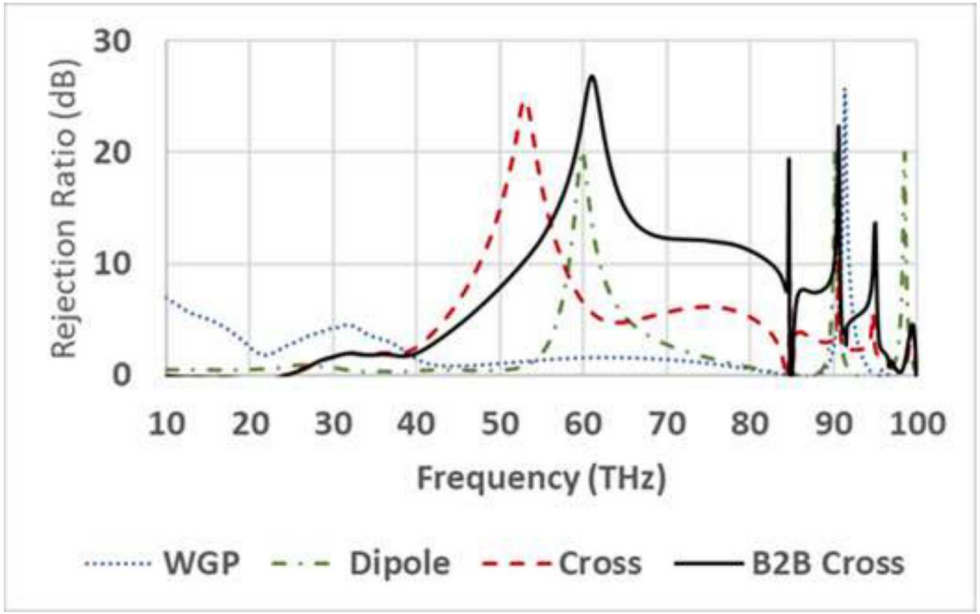
Back-to-Back Vertical Cross WGP

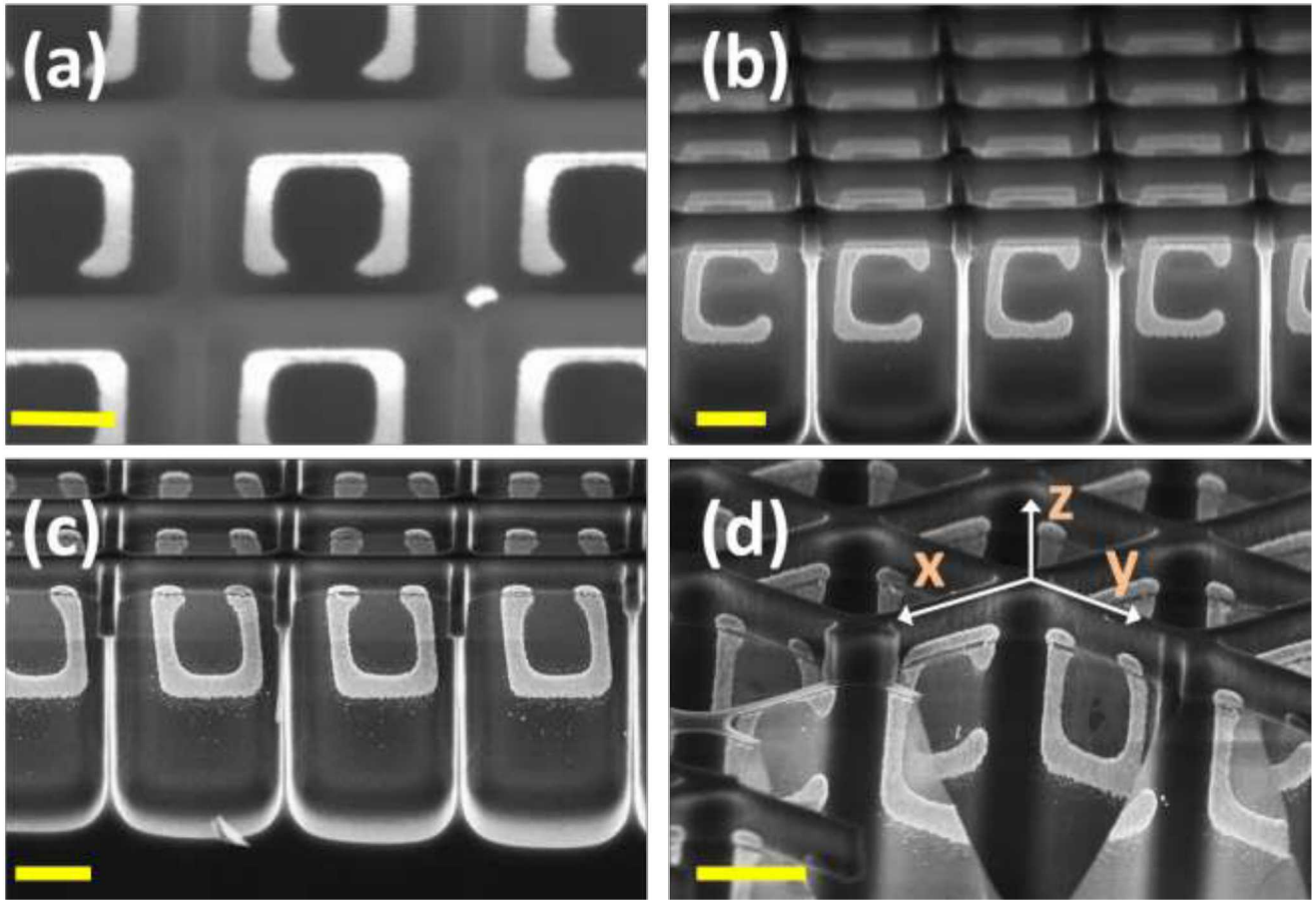


Rejection Ratio = $10 \cdot \mathrm{Log}(T_{passed}/T_{rejected})$



Vertical Split Ring Resonators

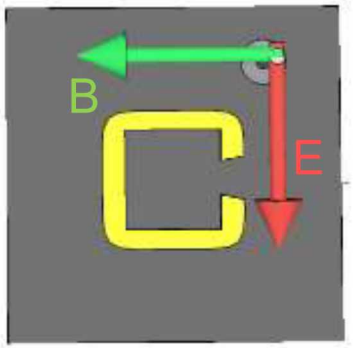
Cubic Unit Cells with 1-SRR and 2-SRR Bases



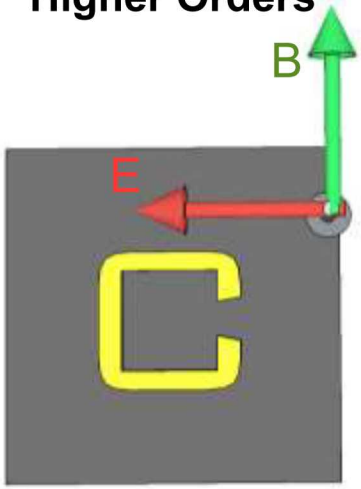
D. Bruce Burckel, Salvatore Campione, Paul S. Davids, and Michael B. Sinclair, "Three dimensional metafilms with dual channel unit cells," Applied Physics Letters, 110, 143107, (2017).

Coupling to SRRs

Planar SRRs



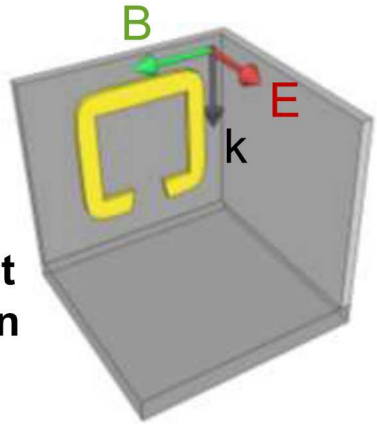
LC Resonance + Higher Orders

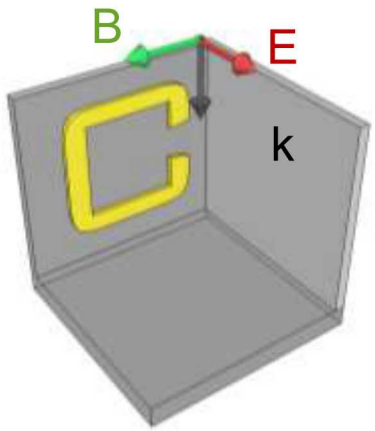


Higher Order Resonances

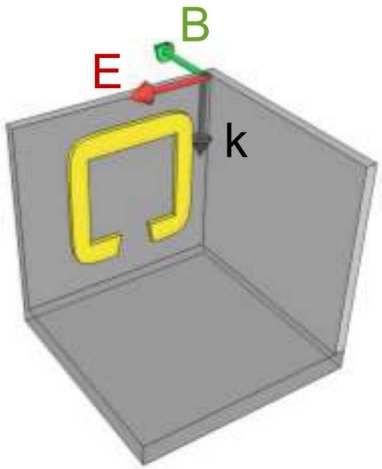
Vertical SRRs

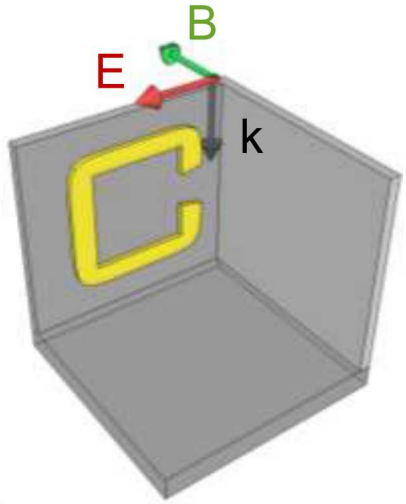
Transparent Polarization





Resonant Polarization





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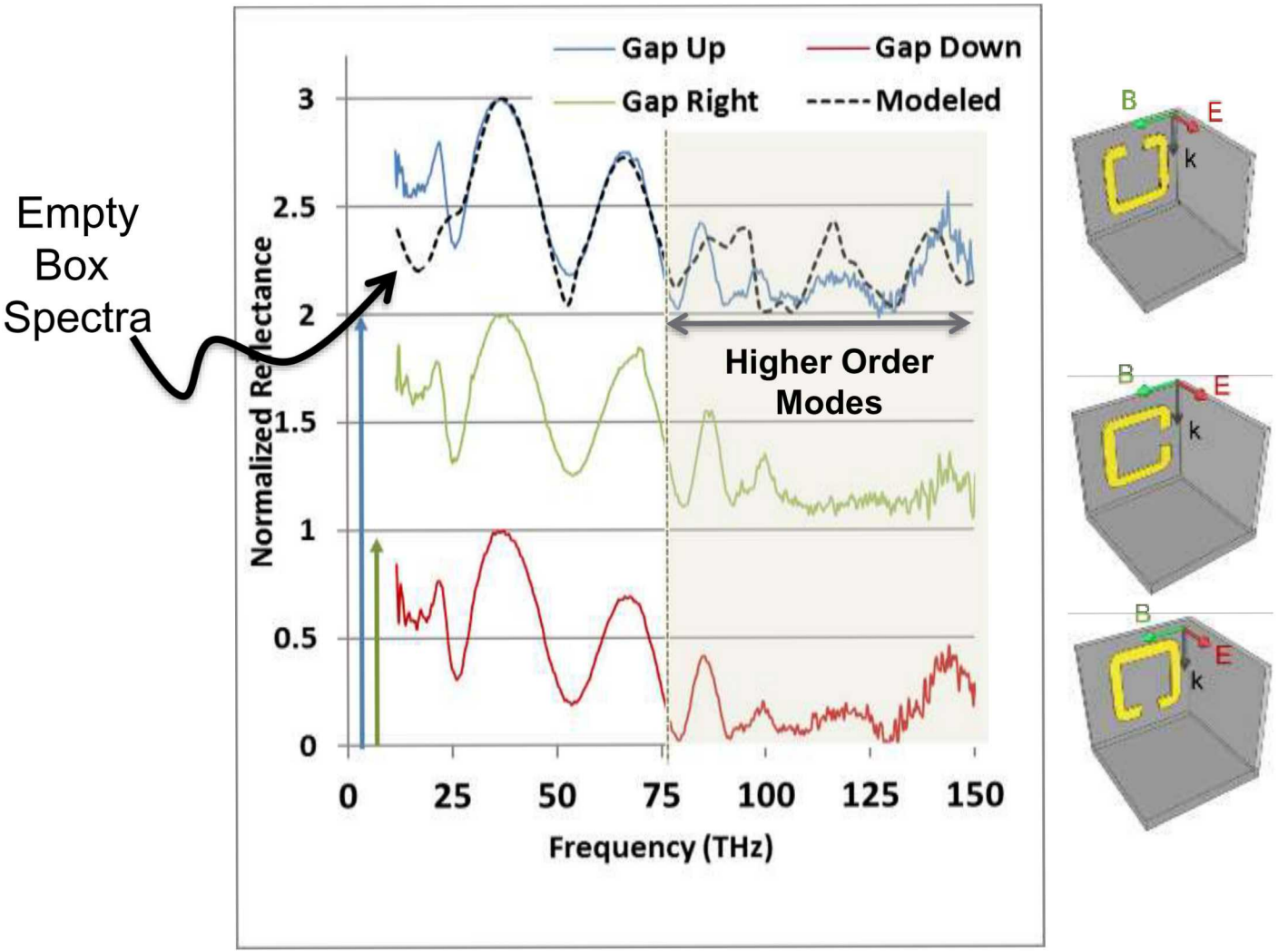
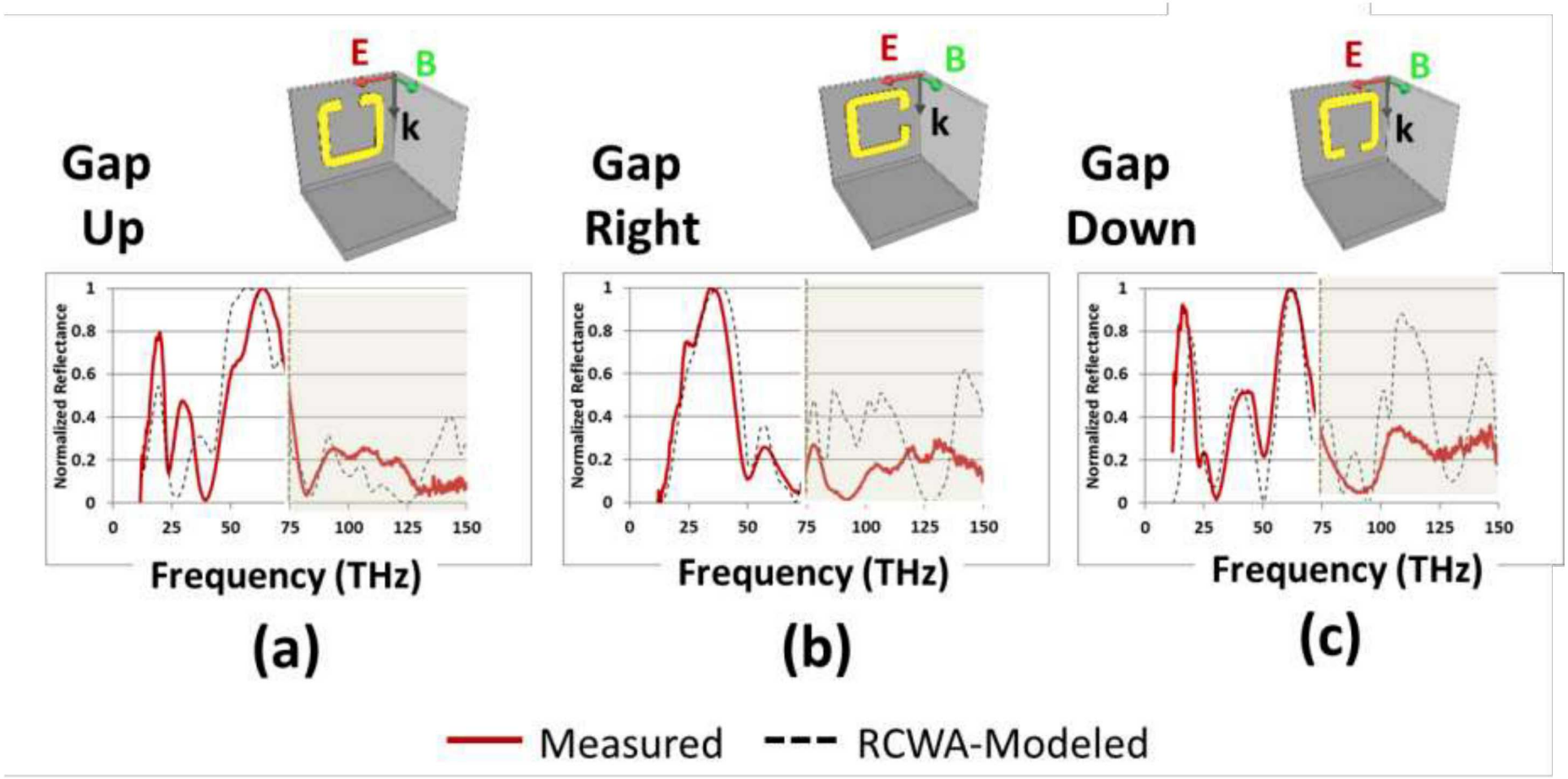
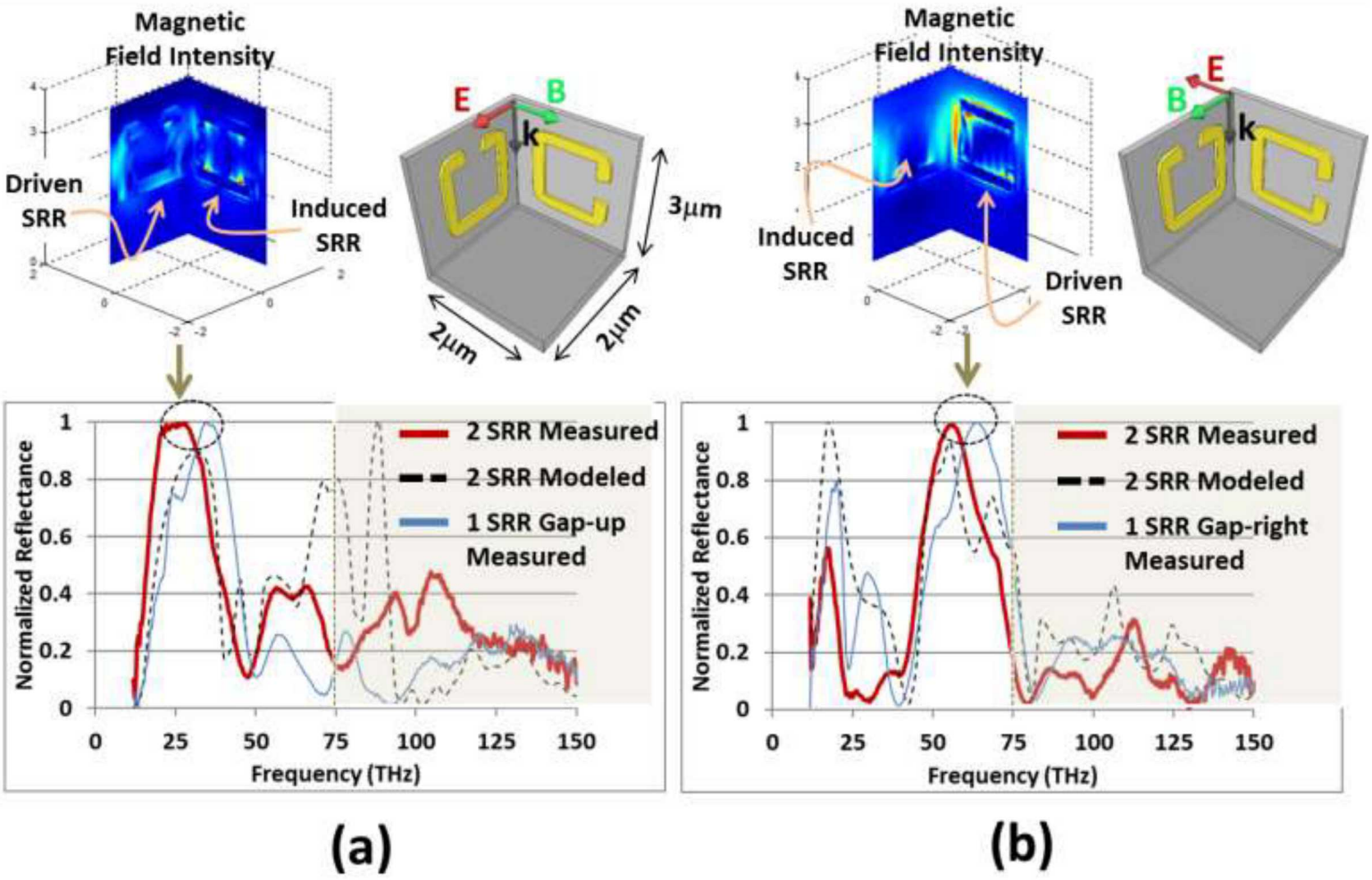


Resonant Polarization

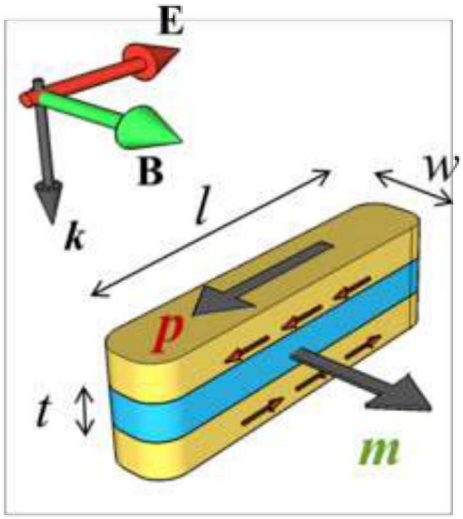


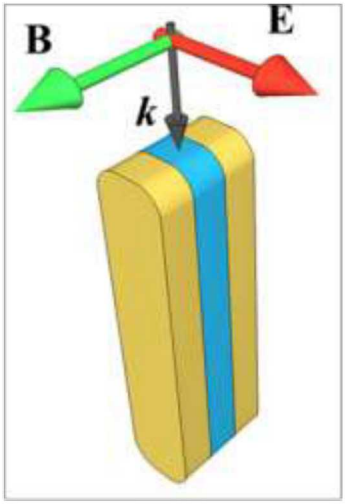
2-SRR Basis Unit Cell – Two Channels

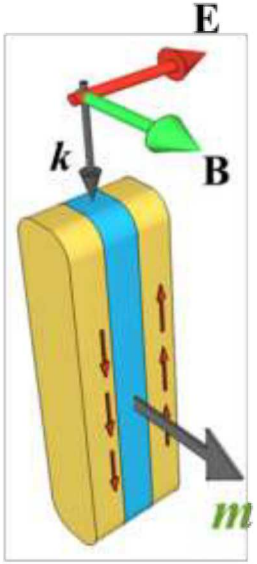


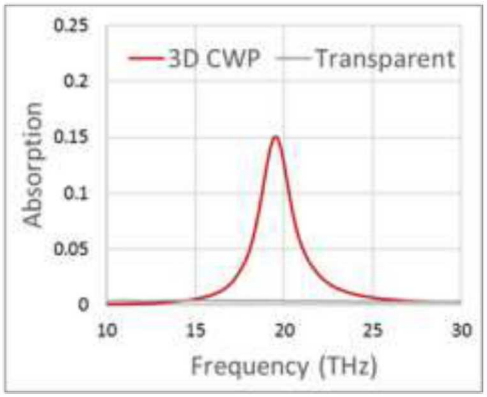
3D Cut-Wire Pair Coupling Mechanism

Comparing Planar CWPs to Vertically Oriented CWPs









a) Planar CWP

b) Transparent Polarization

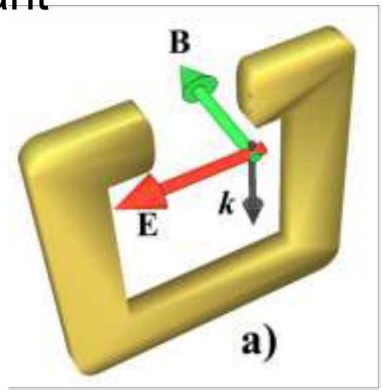
c) 3D CWP

d) Calculated Absorption Spectra

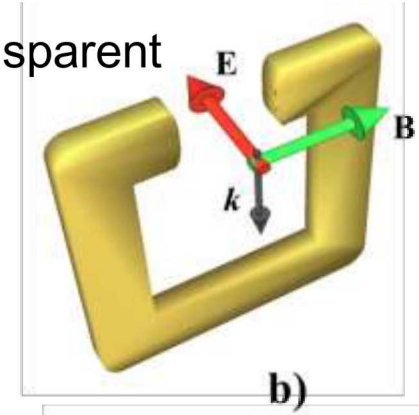
D. Bruce Burckel, Bryan M. Adomanis, Michael B. Sinclair and Salvatore Campione, "Three-dimensional cut wire pair behavior and controllable bianisotropic response in vertically oriented meta-atoms," Optics Express, 25, 32198-32205, (2017).

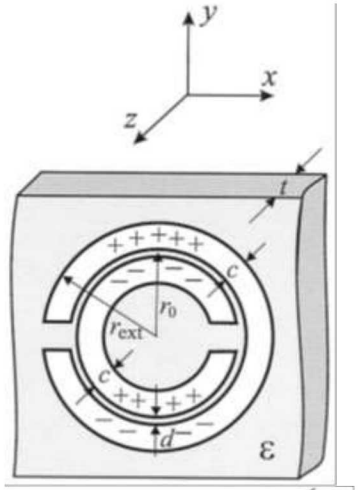
Back-to-Back Vertical SRRs

Resonant

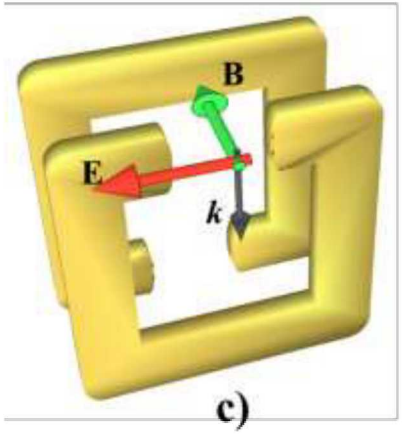


Transparent

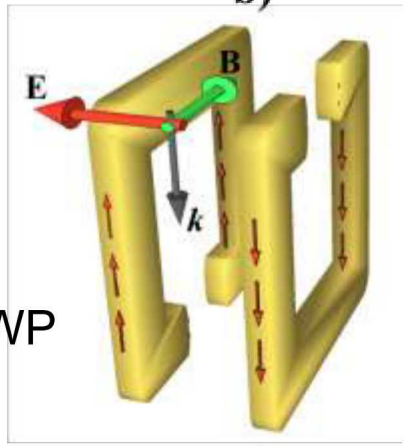


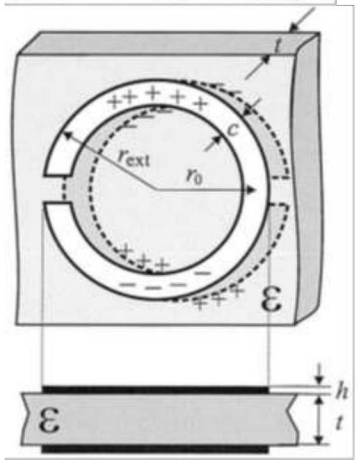


Resonant



3D CWP





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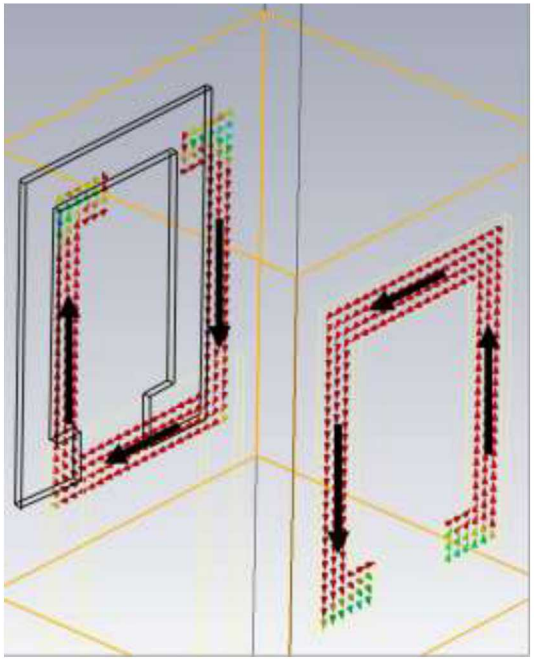
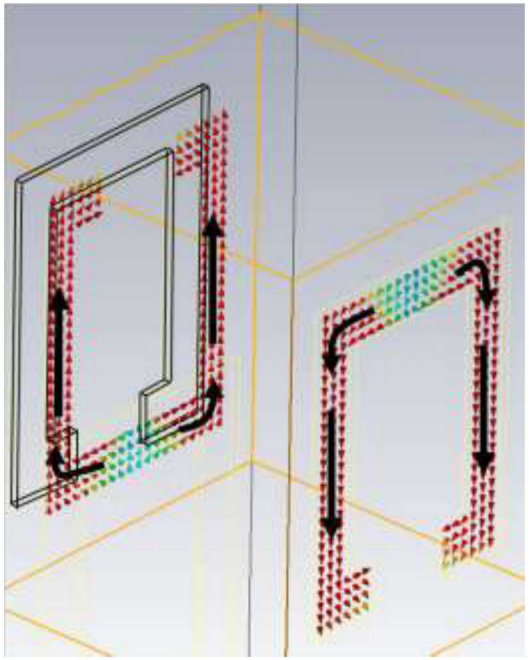
Current Flow for B2B SRRs

Resonant Polarization

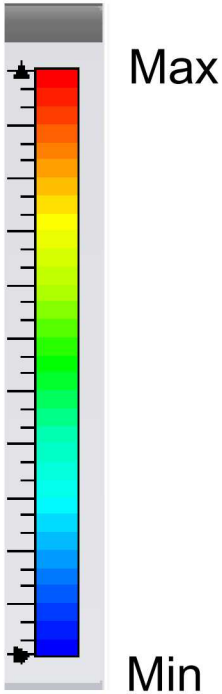


a)

3D CWP Polarization

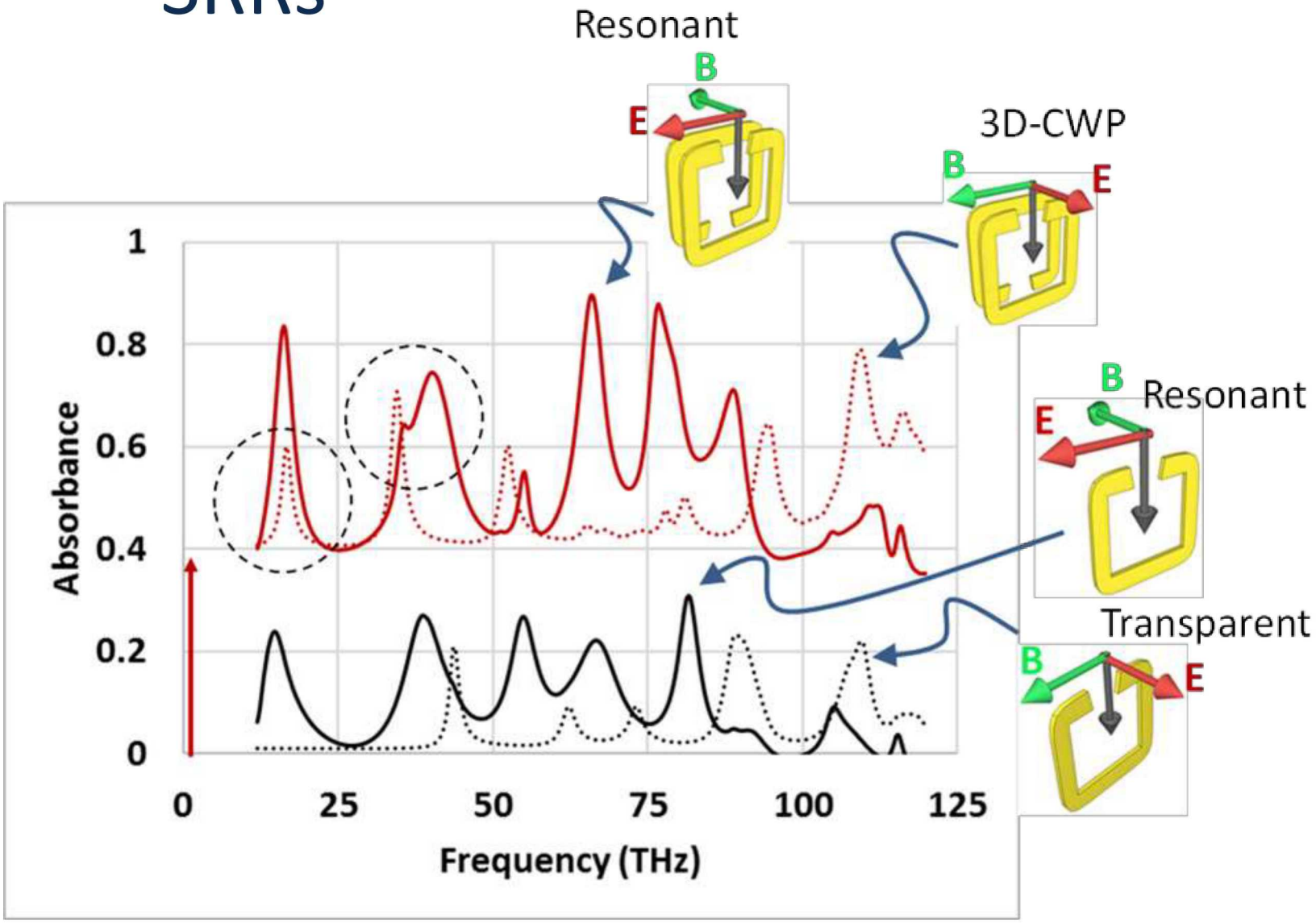


b)

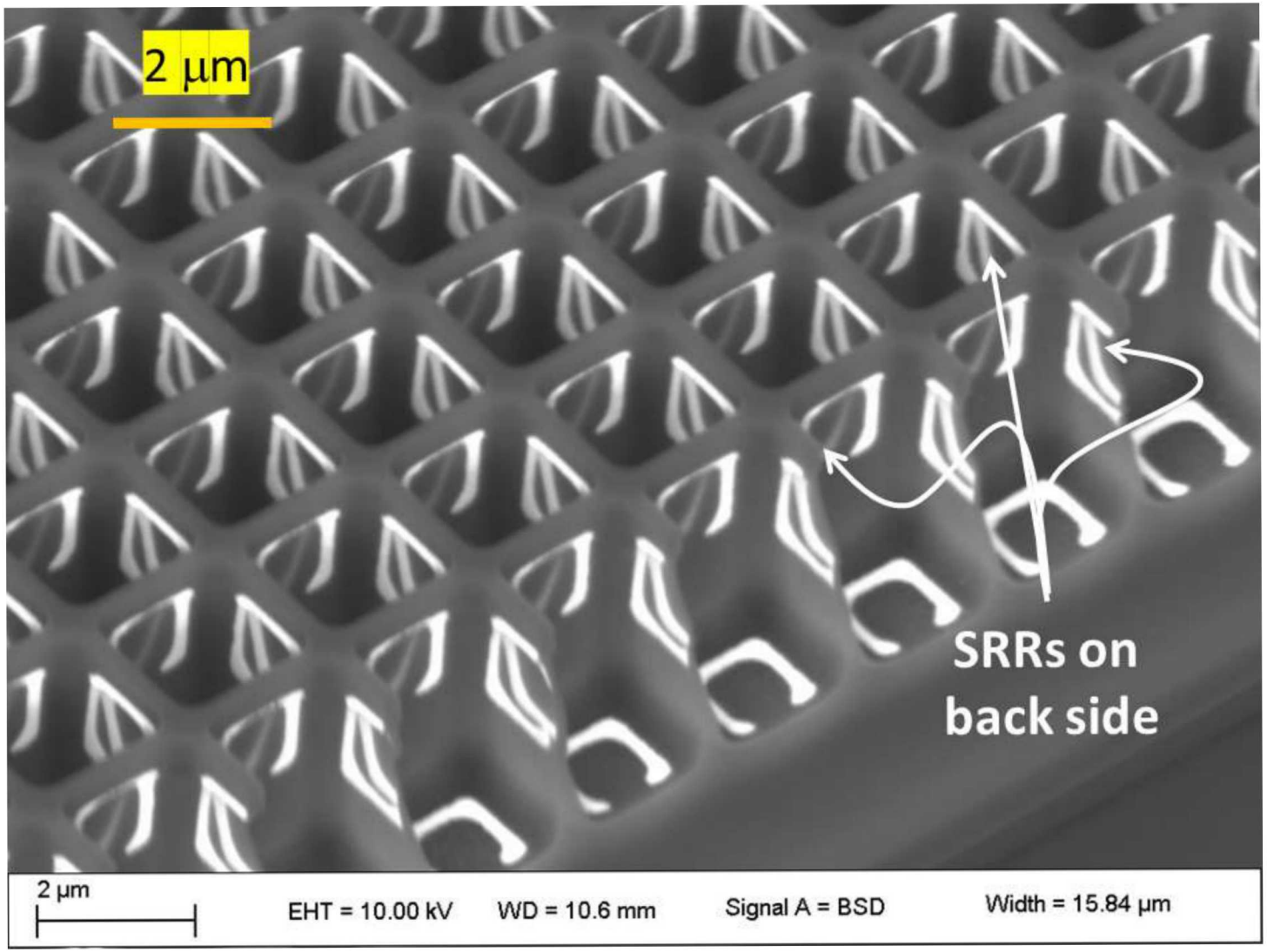


Submitted for publication

Scattering Response for B2B SRRs

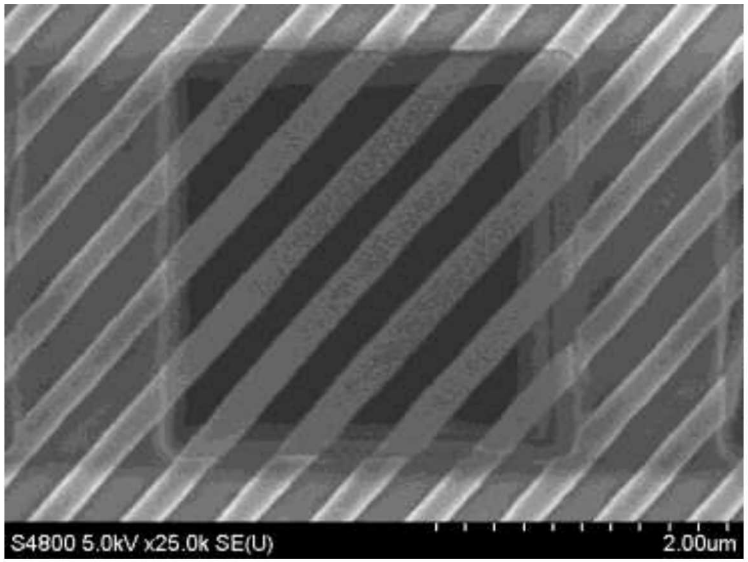


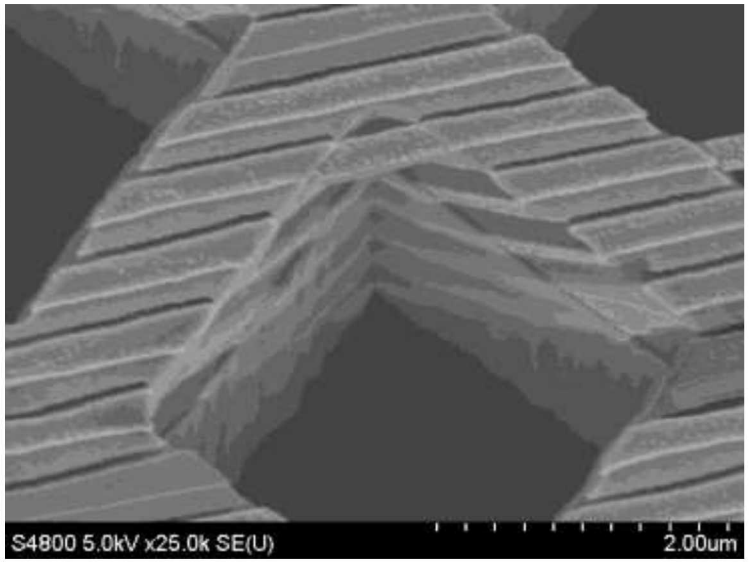
Dense Metafilm Arrays

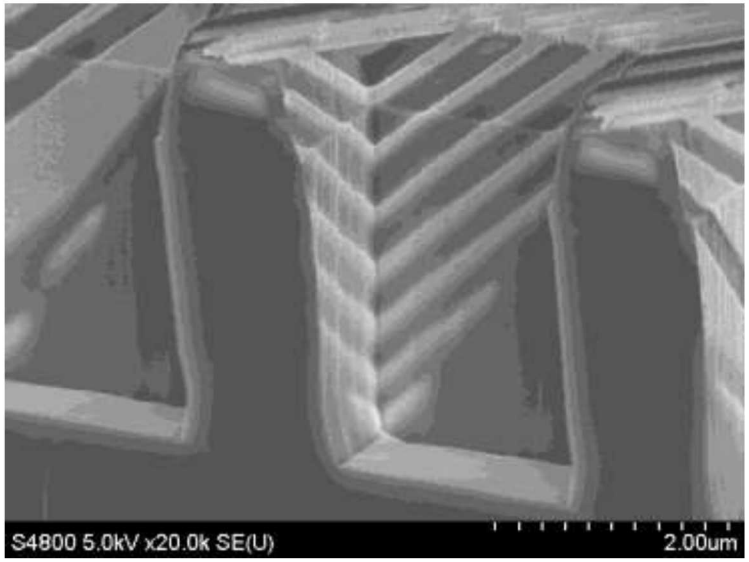


Truly 3D Meta-atoms - Chevrons

IL – 3D Chevrons







Summary

1. Membrane projection lithography is a versatile fabrication approach capable of fabricating a wide range of 3D metamaterial structures in CMOS compatible material systems.

2. Vertically oriented inclusions demonstrate coupling behaviors which cannot be duplicated by planar structures.

3. Even though CWP and SRRs have been studied for more than 10 Years, there are still subtleties to their scattering behavior which will impact how they perform in next-generation 3D metamaterial components.

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