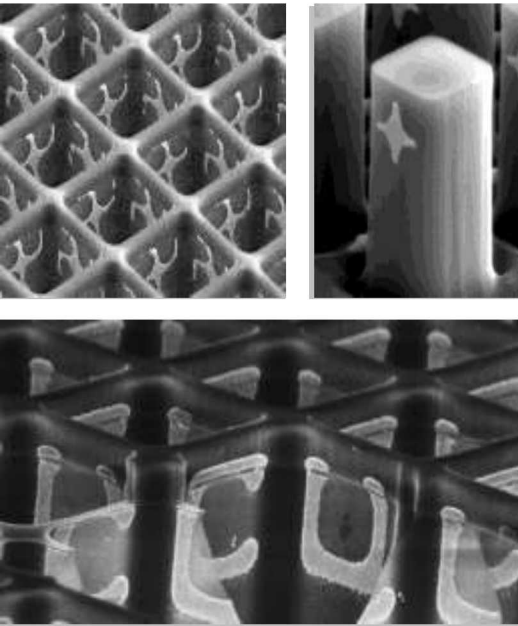




This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

SPIE Optics and Photonics 2013 SAND2019-10743C



Coupling effects in dense arrays of 3D optical metamaterials

August 19, 2018

Bruce Burckel

dbburck@sandia.gov



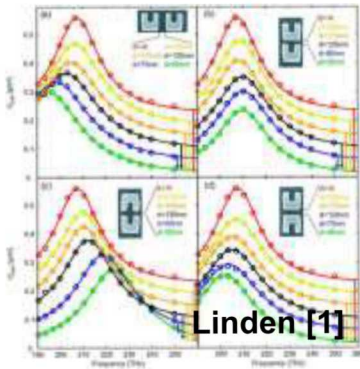
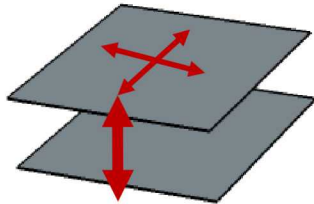
*Exceptional
service
in the
national
interest*



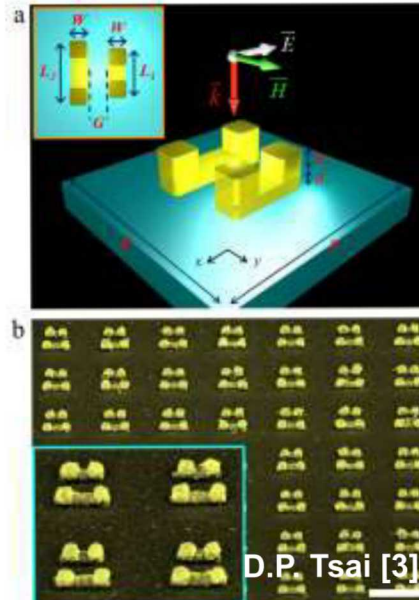
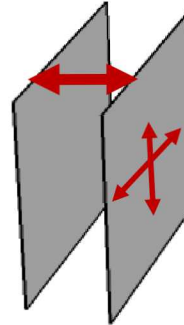
Sandia National Laboratories is a multi mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525

Comparing Coupling Mechanisms in Planar and Vertical Structures

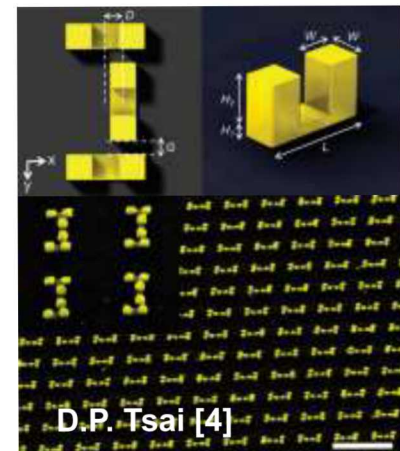
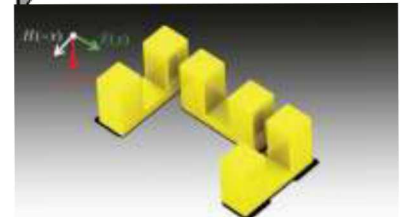
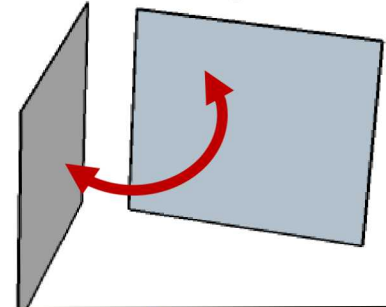
Stacked Planar Geometry



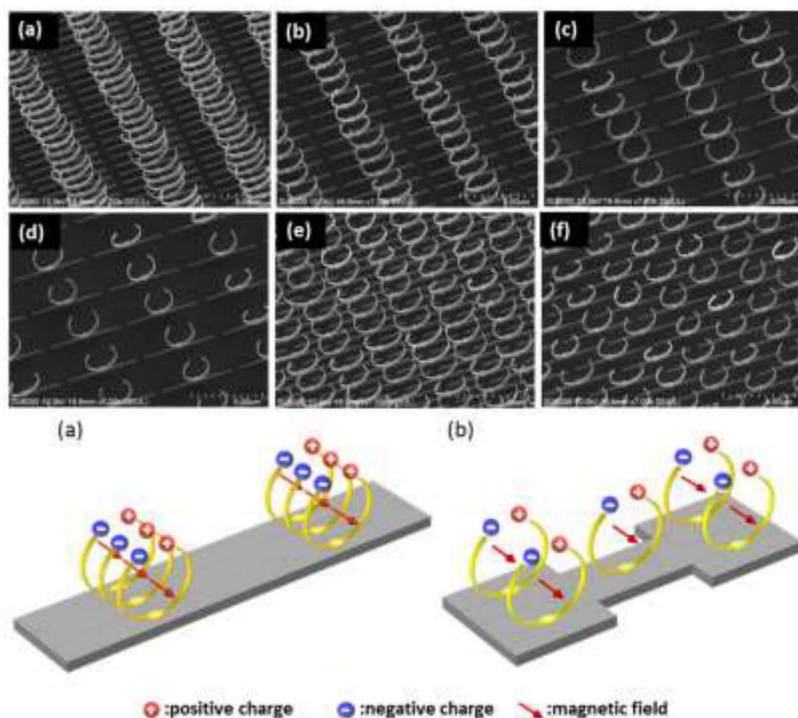
Back-to-back Vertical Geometry



Orthogonal Vertical Geometry

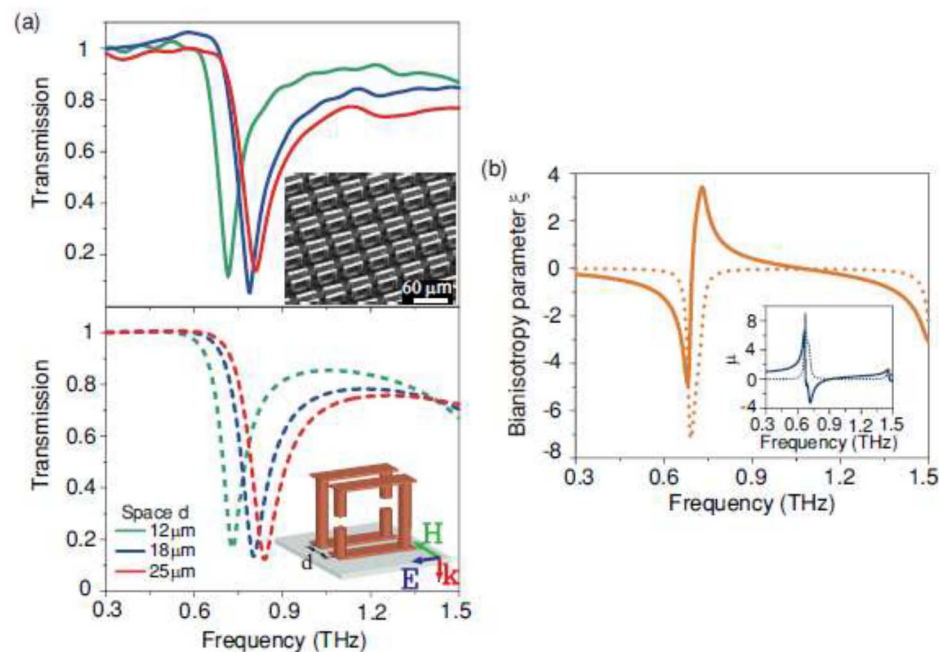


Horizontally Oriented Magnetic Dipole



Tanaka and Chen [5]

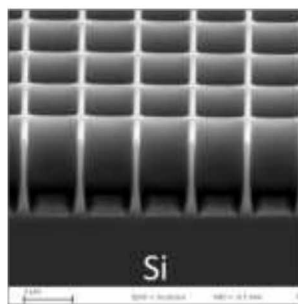
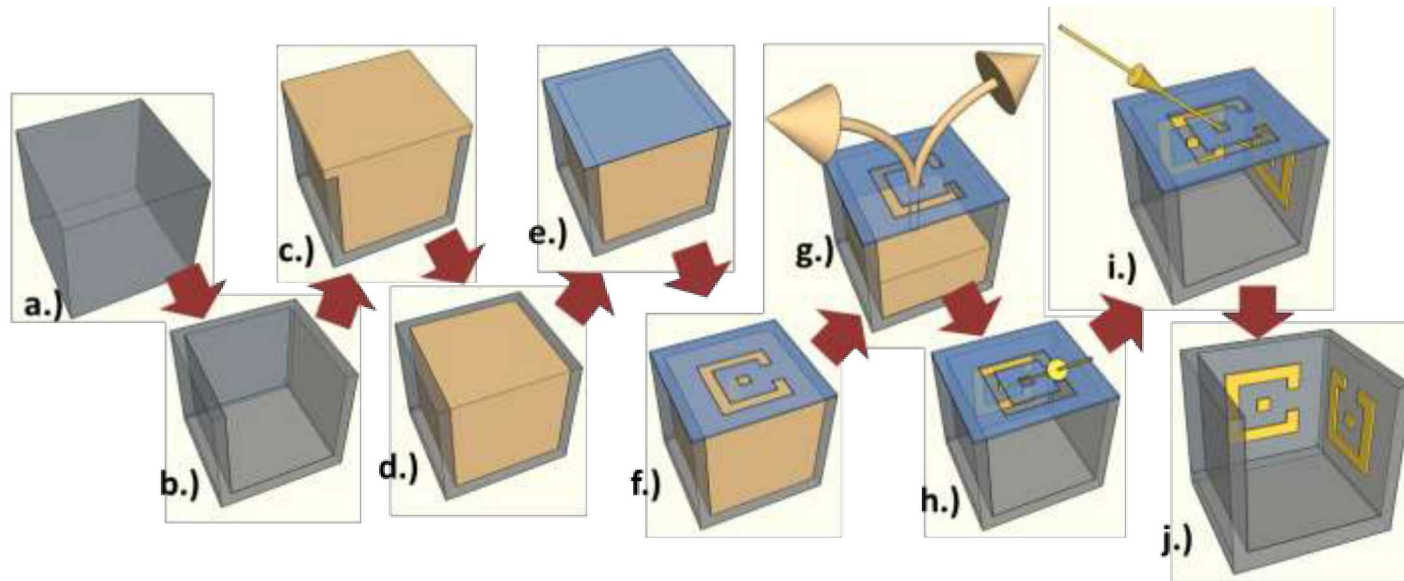
Unambiguous Coupling to Normally Incident Magnetic Field



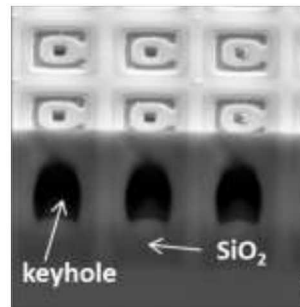
Averitt [6]

Membrane Projection Lithography (MPL)

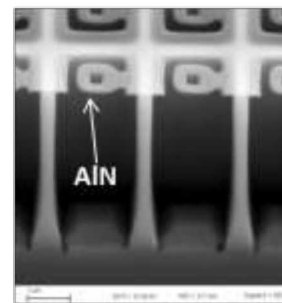
3D Micron-scale Fabrication Approach



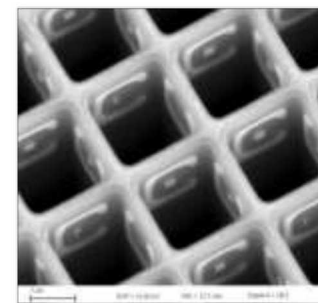
k.)



l.)



m.)

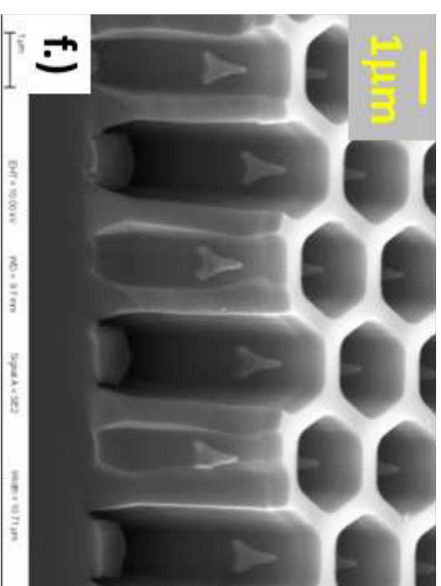
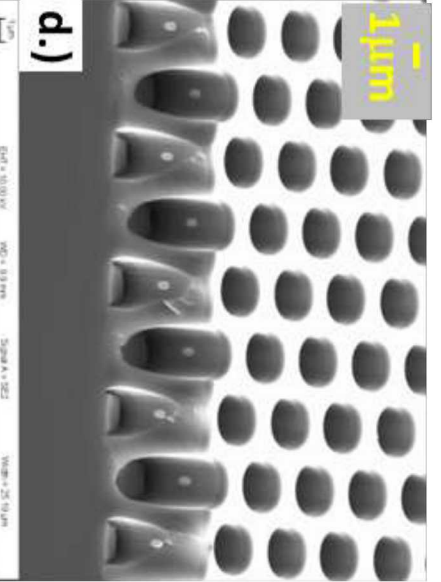
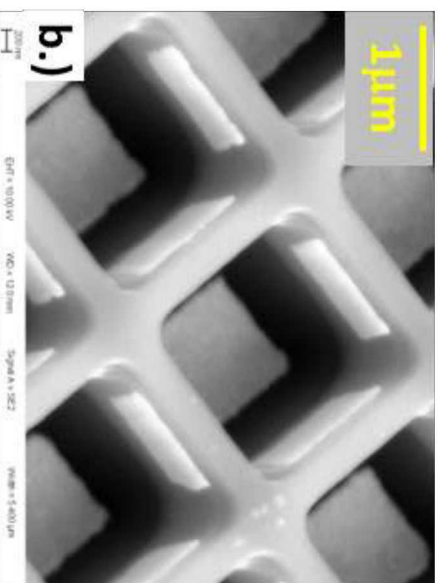
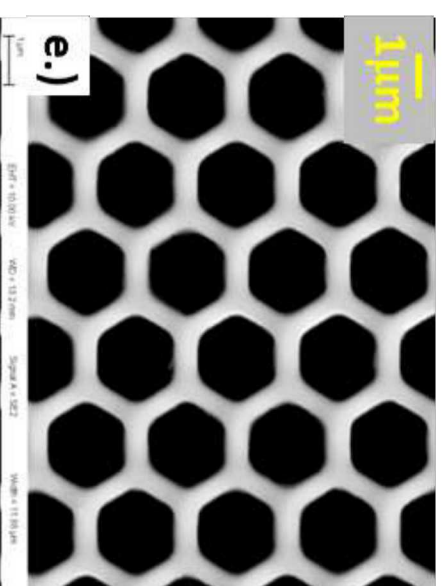
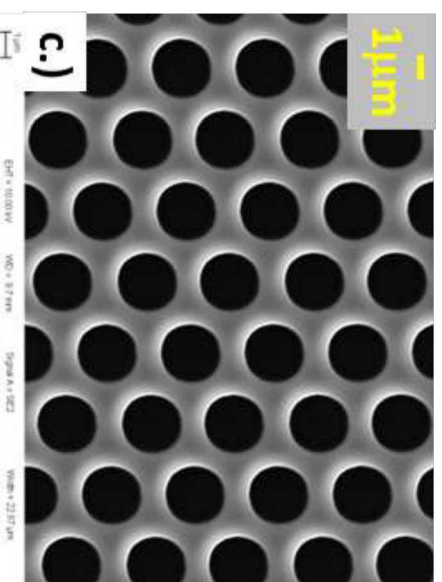
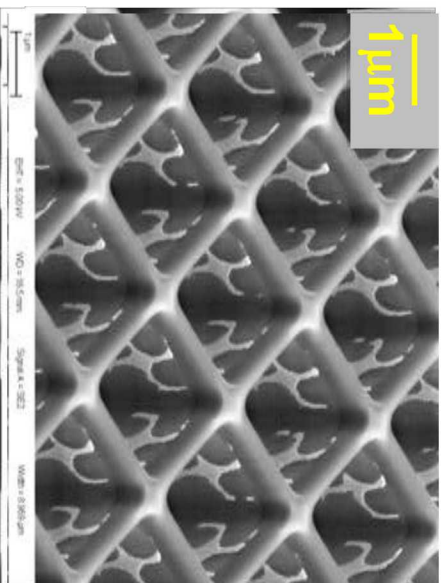


n.)

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).



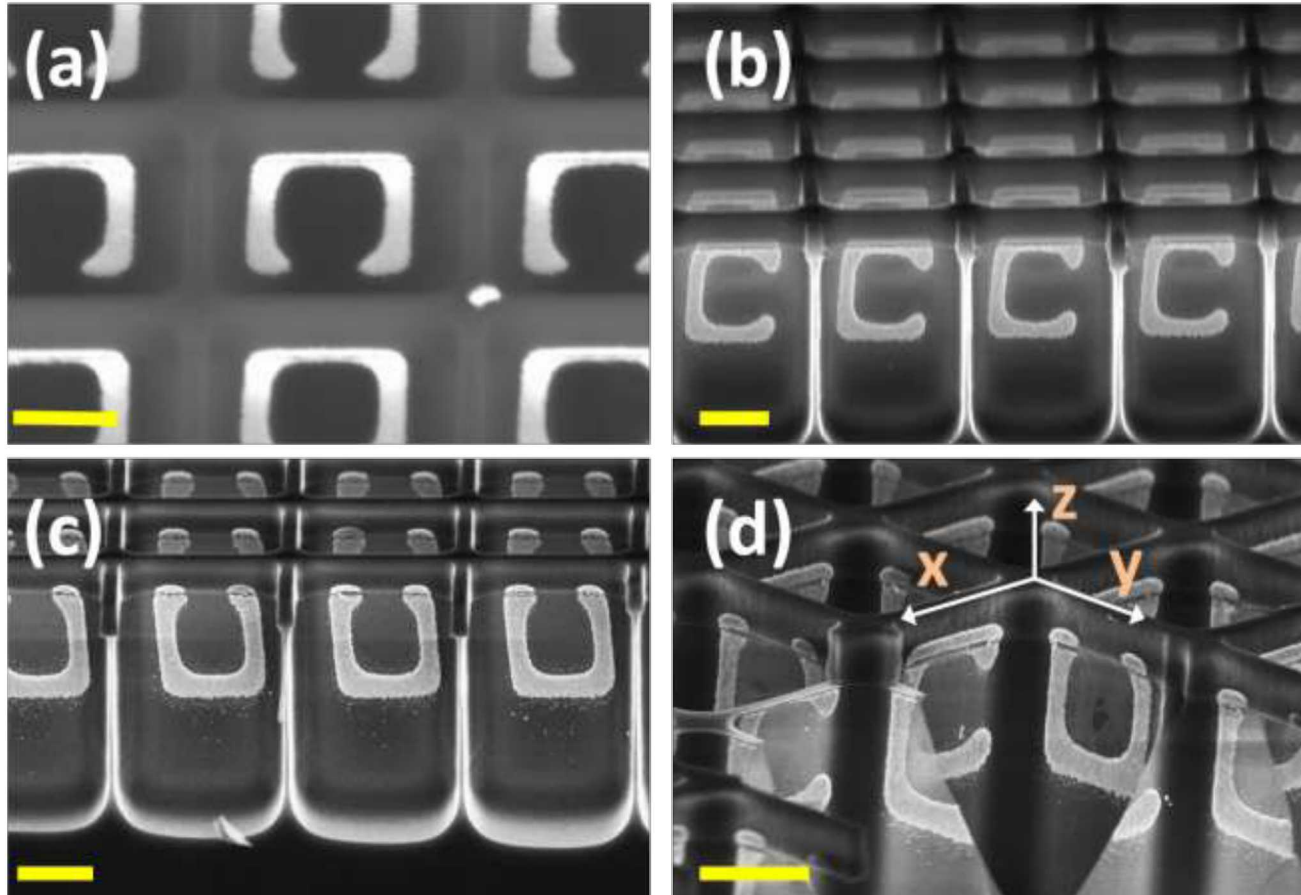
3D micron-scale Metamaterials





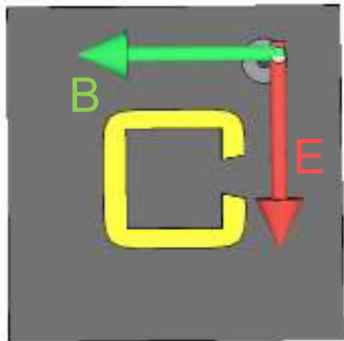
Vertical Split Ring Resonators

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

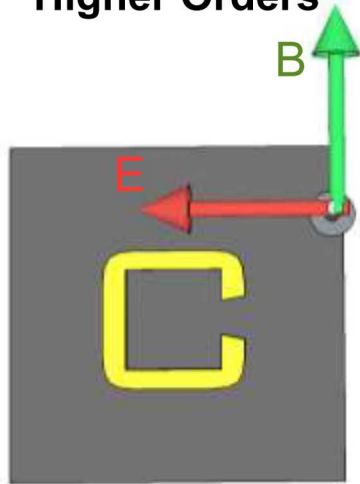


D. Bruce Burckel, Salvatore Campione, Paul S. Davids, and Michael B. Sinclair, "Three dimensional metafilms with dual channel unit cells," *Applied Physics Letters*, 110, 143107, (2017).

Planar SRRs

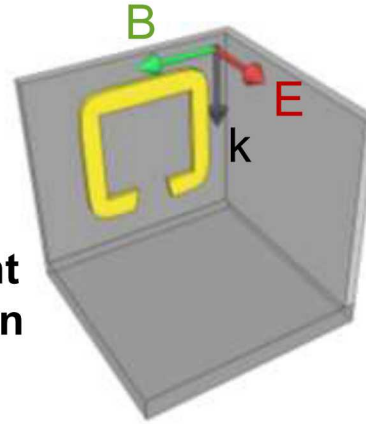


LC Resonance +
Higher Orders

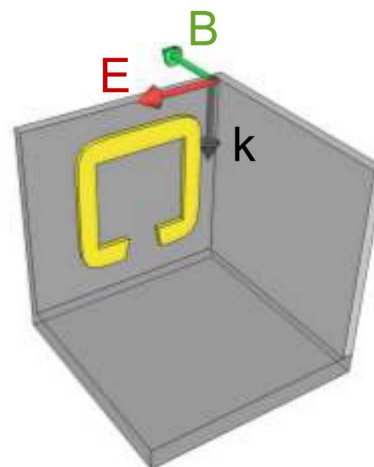
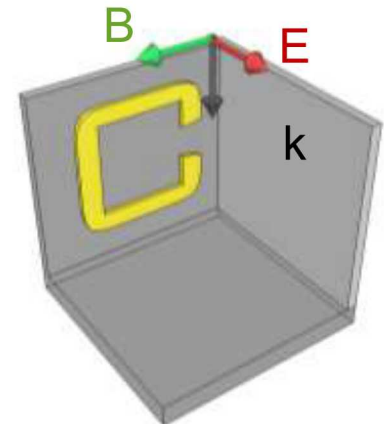


Higher Order
Resonances

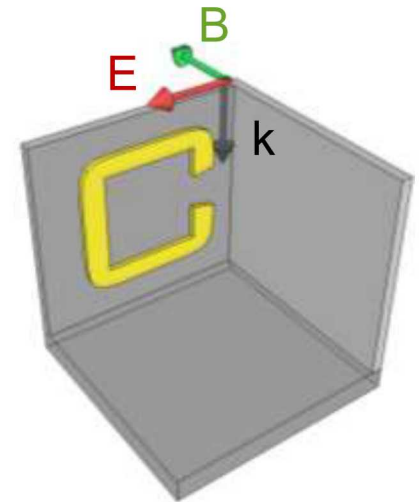
Vertical SRRs

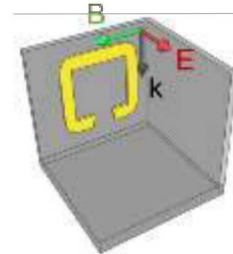
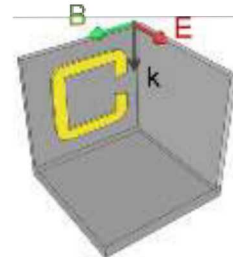
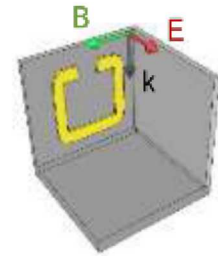
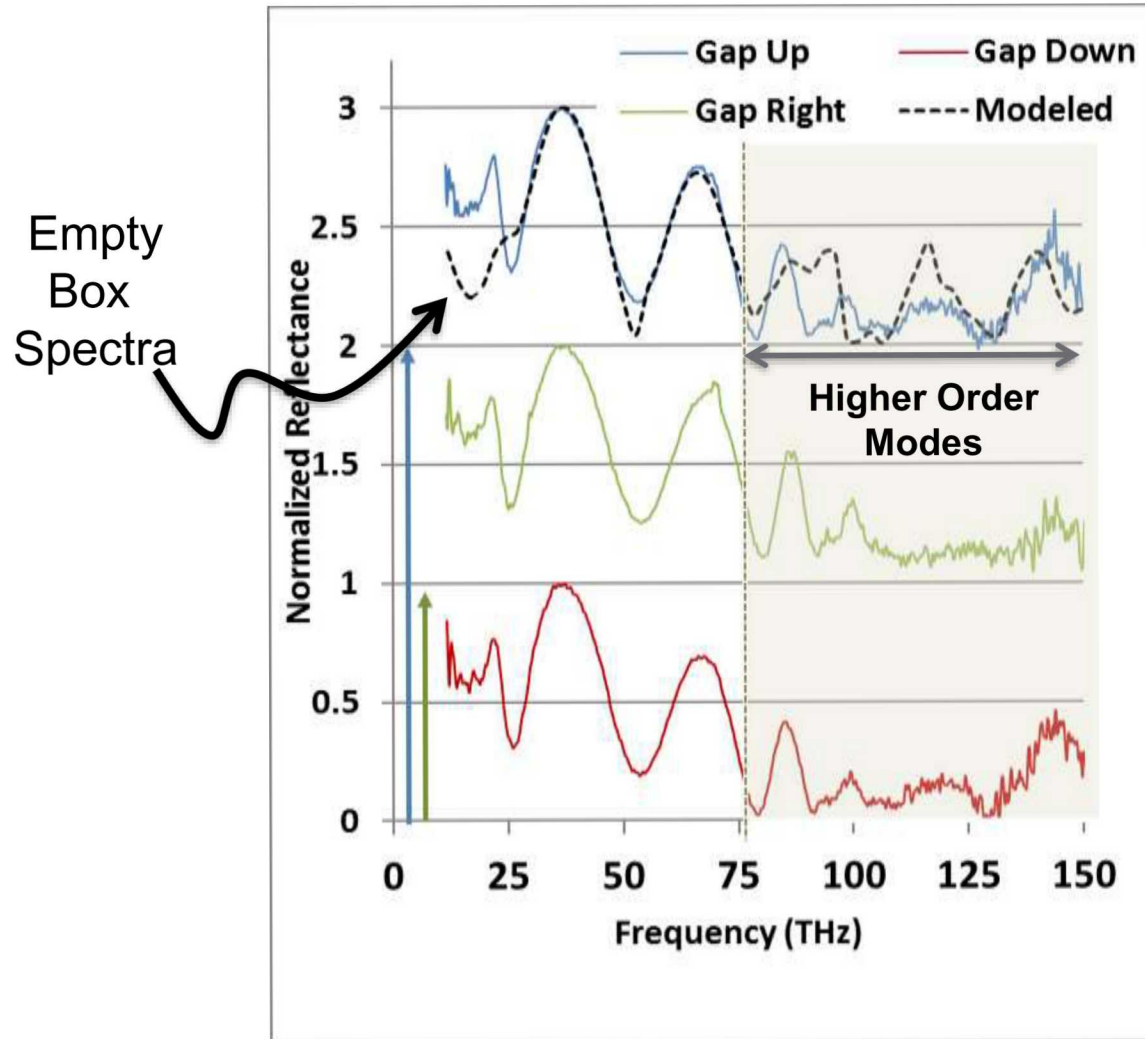


Transparent
Polarization

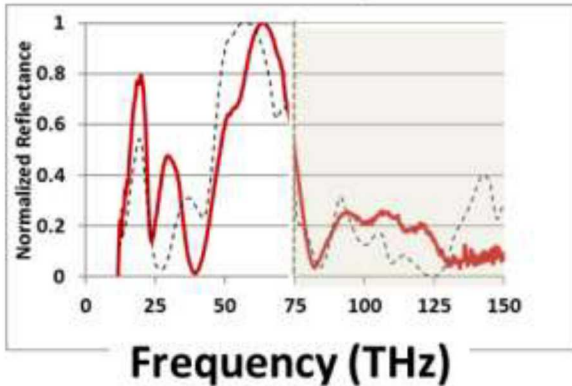
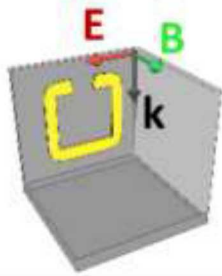


Resonant
Polarization



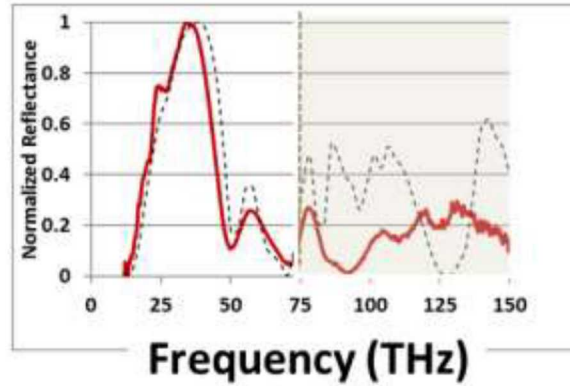
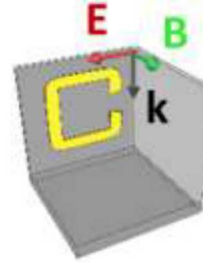


**Gap
Up**



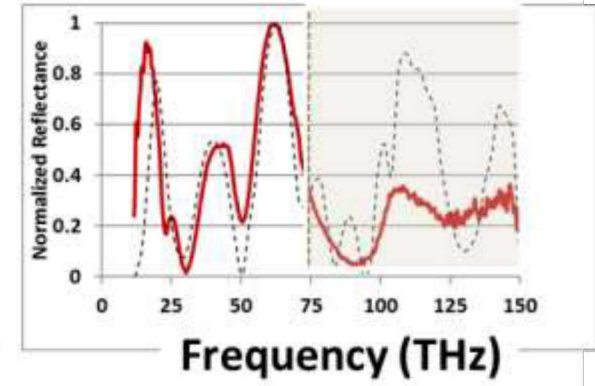
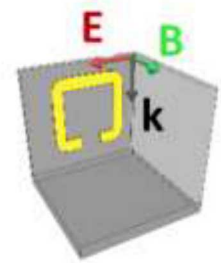
(a)

**Gap
Right**



(b)

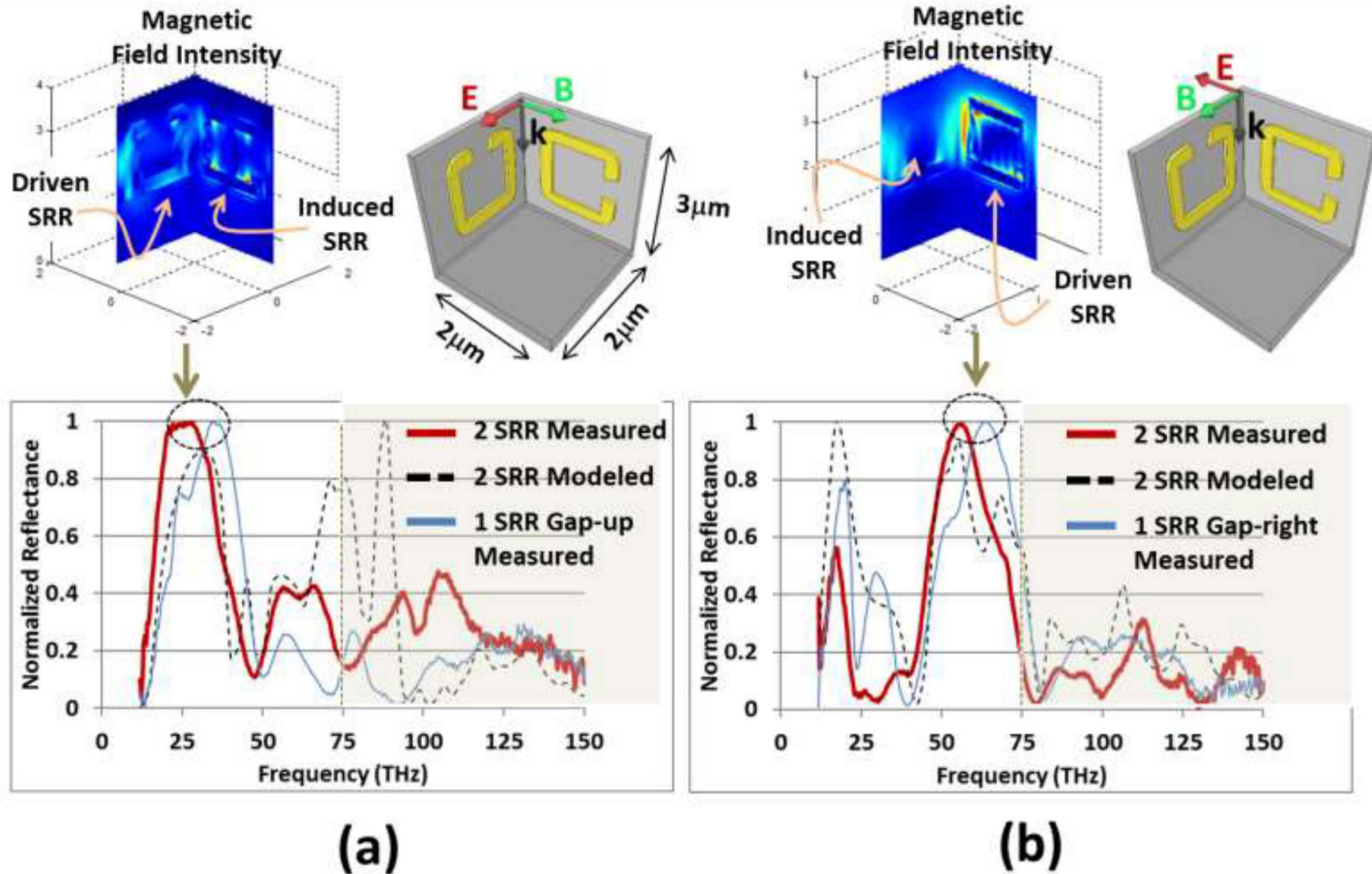
**Gap
Down**



(c)

— Measured --- RCWA-Modeled

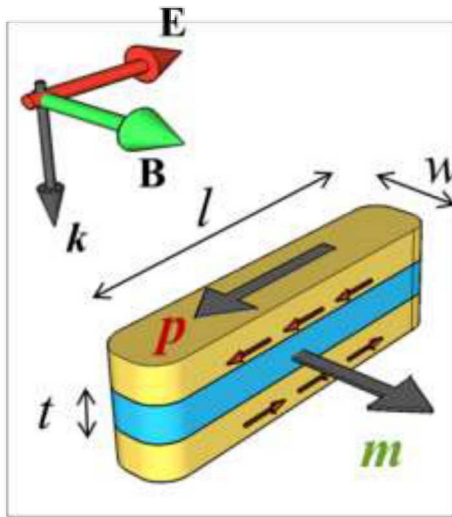
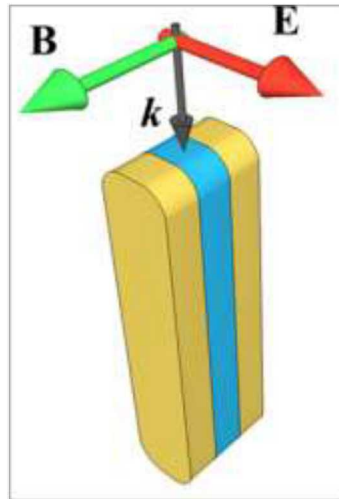
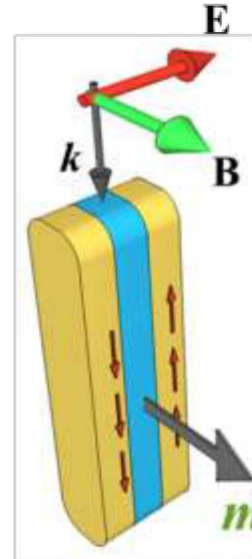
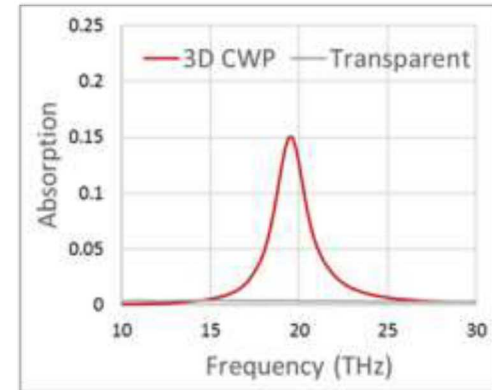
2-SRR Basis Unit Cell – Two Channels





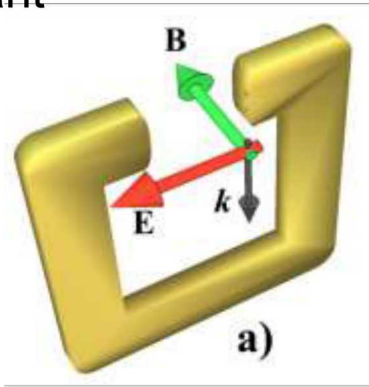
3D Cut-Wire Pair Coupling Mechanism

Comparing Planar CWPs to Vertically Oriented CWPs

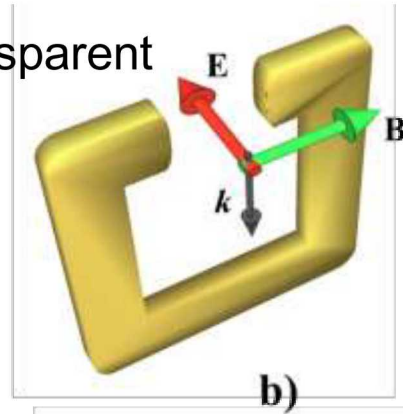
**a)****Planar CWP****b)****Transparent
Polarization****c)****3D
CWP****d)****Calculated
Absorption Spectra**

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).

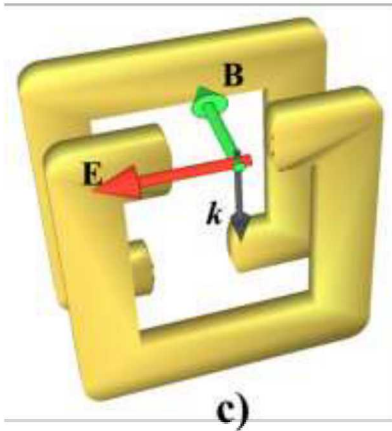
Resonant



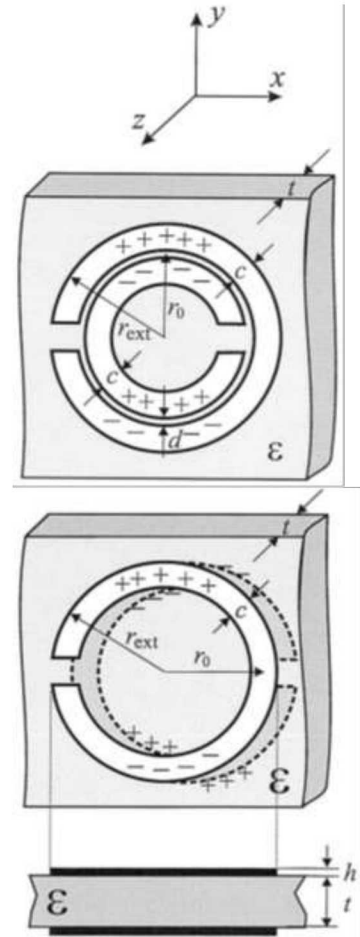
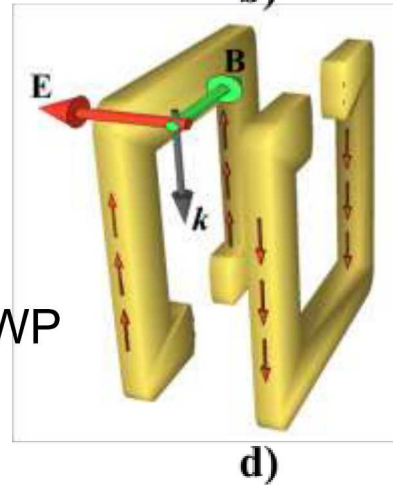
Transparent



Resonant

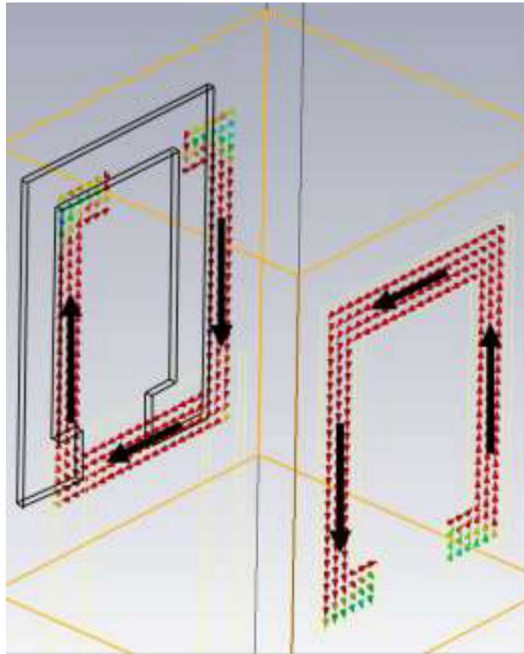


3D CWP



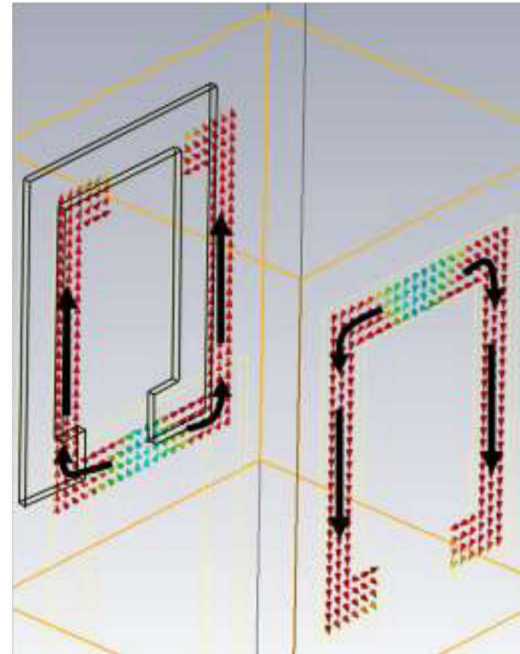
Submitted for publication

**Resonant
Polarization**

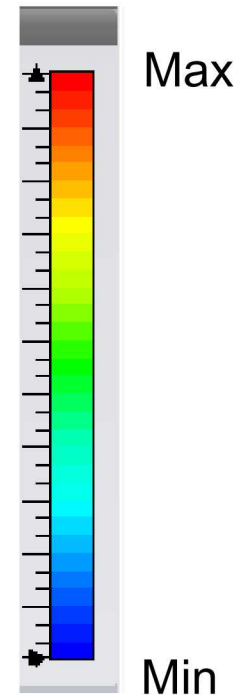


a)

**3D CWP
Polarization**

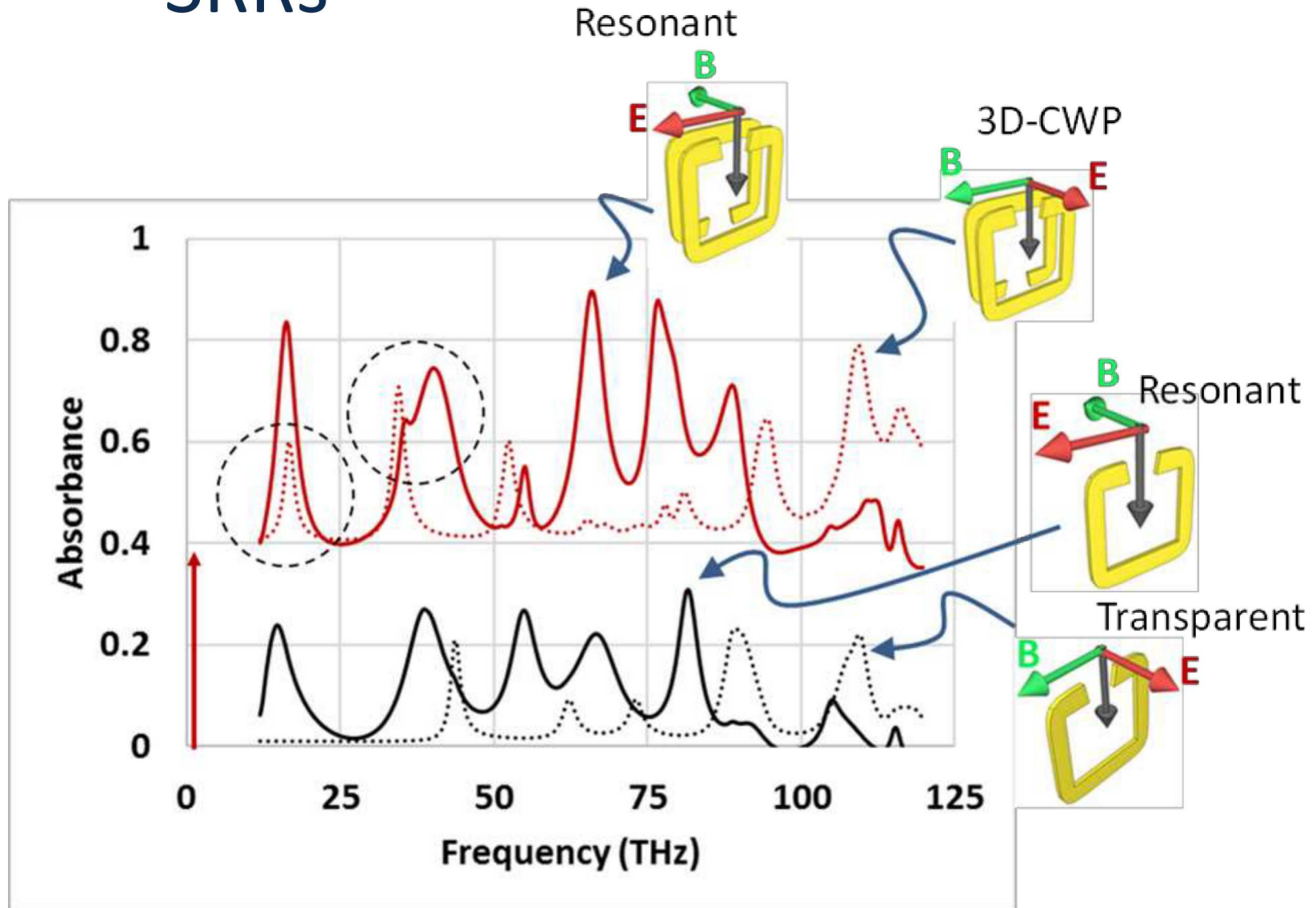


b)

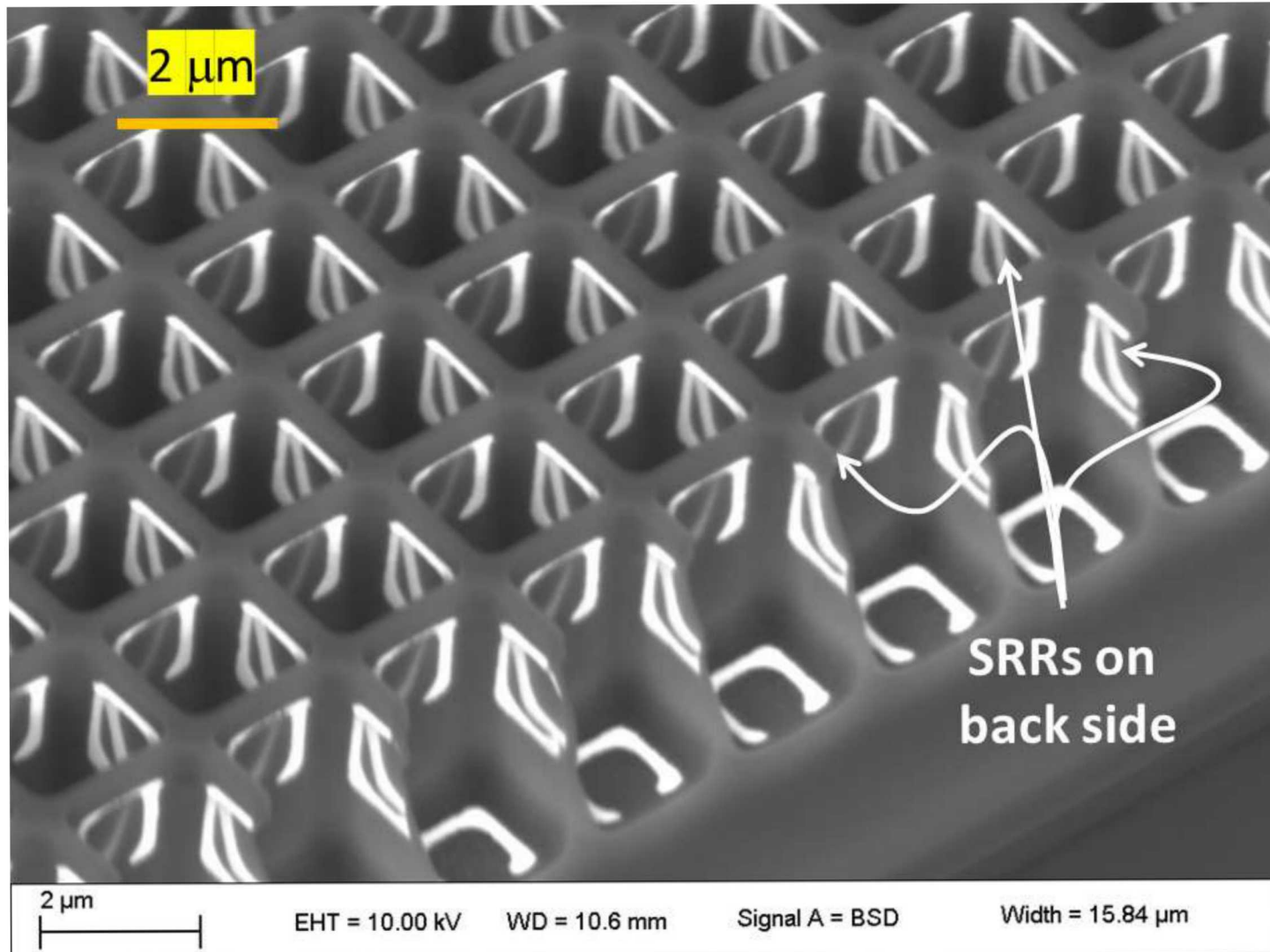


Submitted for publication

Scattering Response for B2B SRRs



Dense Metafilm Arrays





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.