



IEEE RESEARCH AND APPLICATIONS OF PHOTONICS IN DEFENSE

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Plasmonic Response in Three-Dimensional Meta-Films

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1) Sandia National Laboratories, 2) Penn State University



August 4, 2021

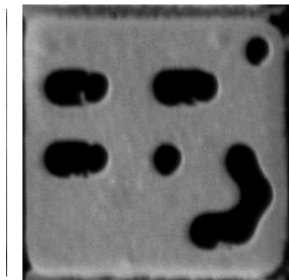
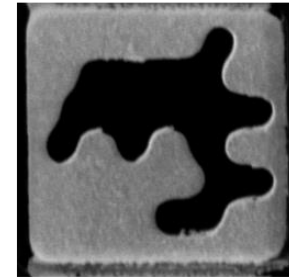
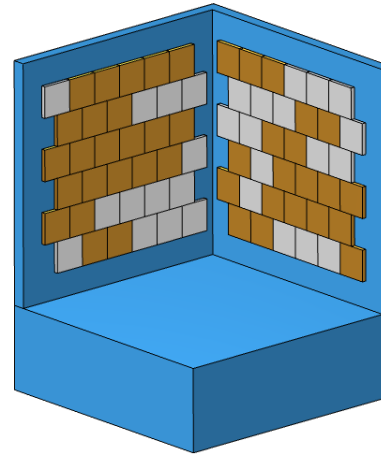
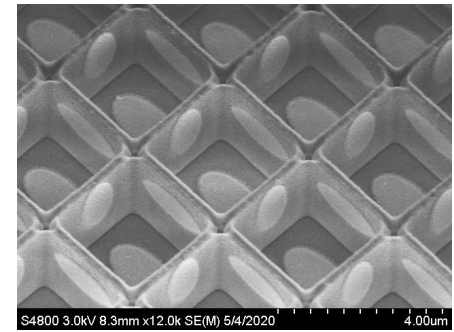
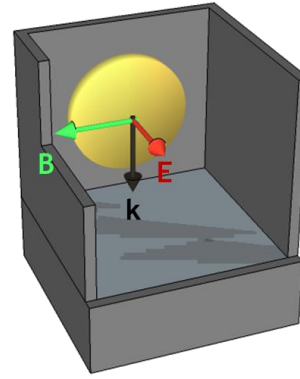
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Outline

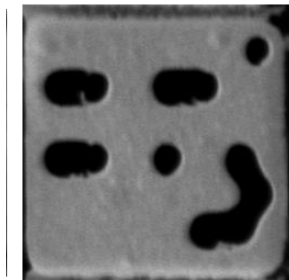
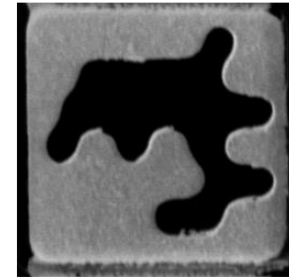
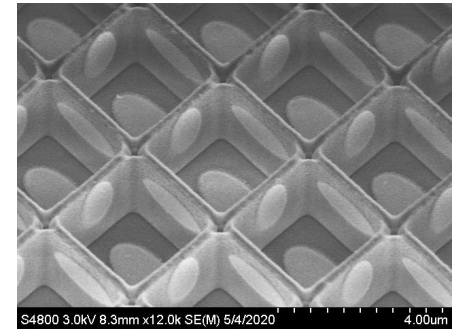
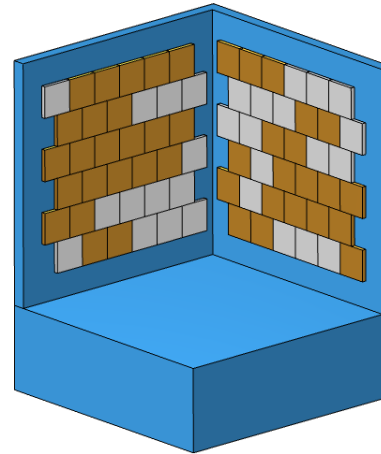
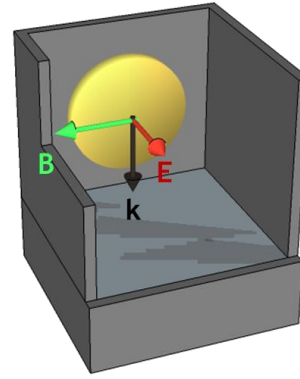
- Why three-dimensional?
- Membrane Projection Lithography
- Vertically oriented ellipses
- Asymmetric transmission
- Multifunction metalenses
 - Single Color
 - Two Color





Outline

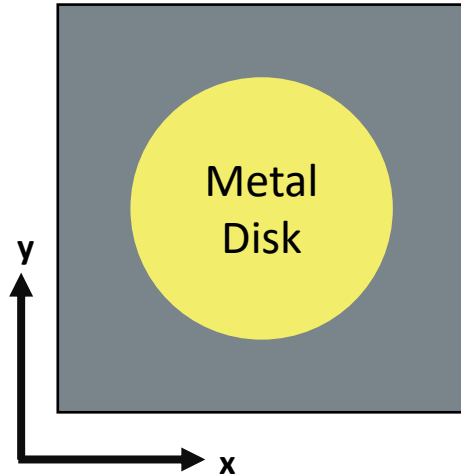
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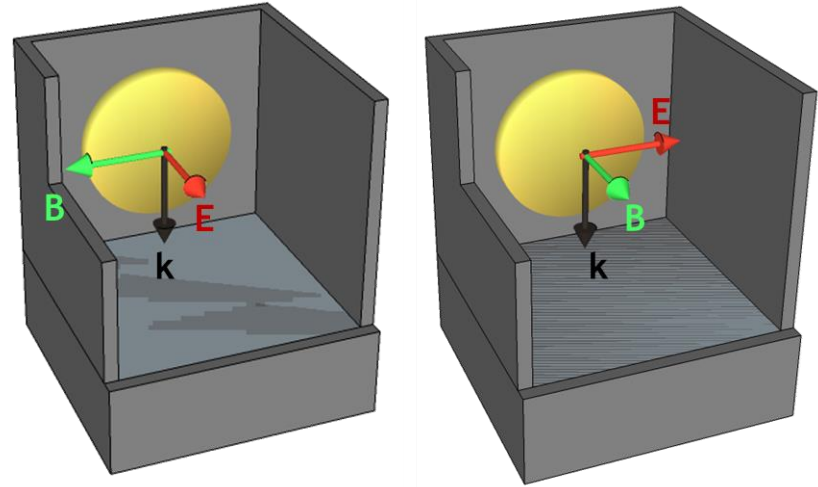
Why three-dimensional?

Planar Metasurface



- Metal disk for electric field along x or y

Three-Dimensional Metasurface

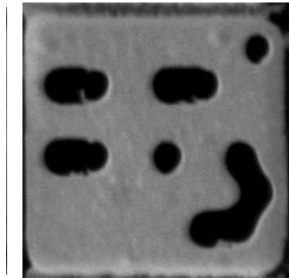
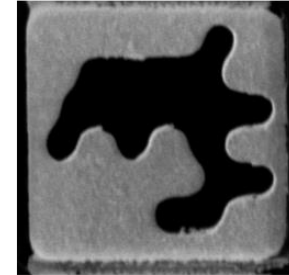
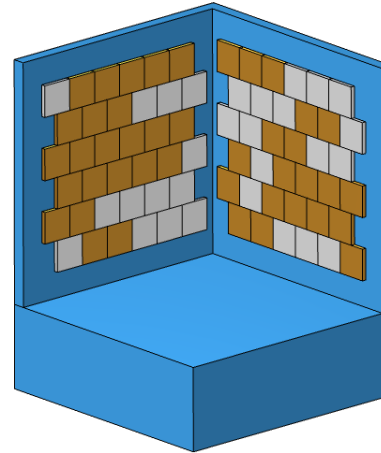
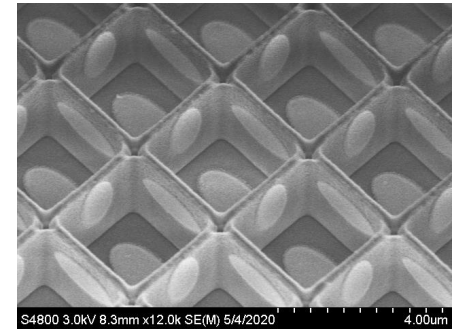
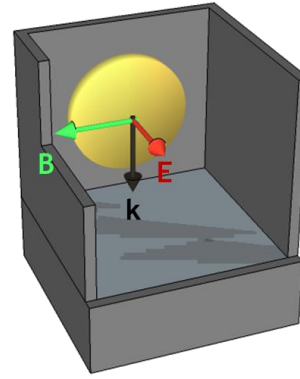


- Metal disk excited for one polarization and transparent for the other
- Decoupled polarization-indexed response



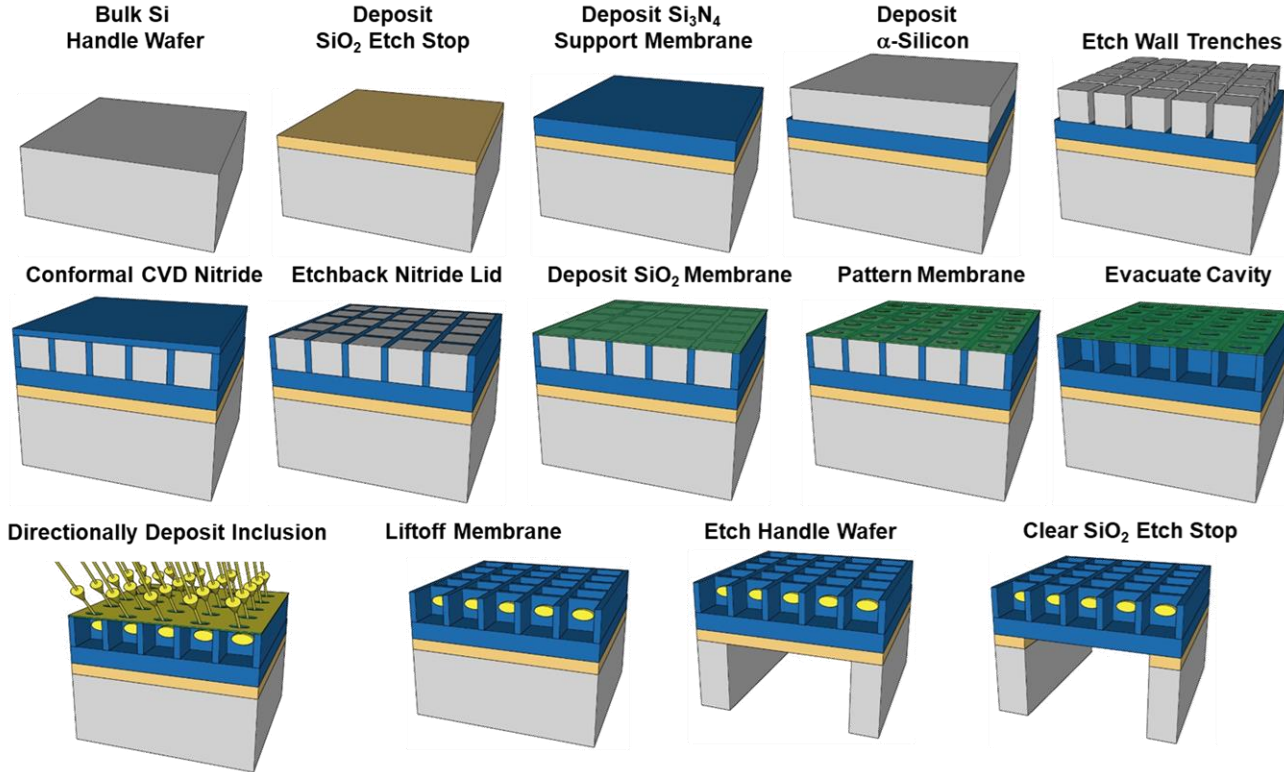
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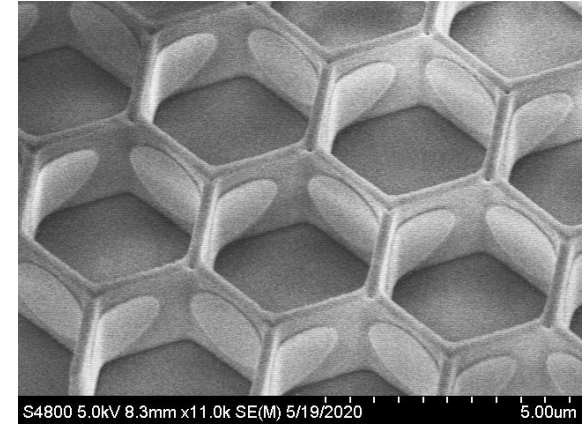
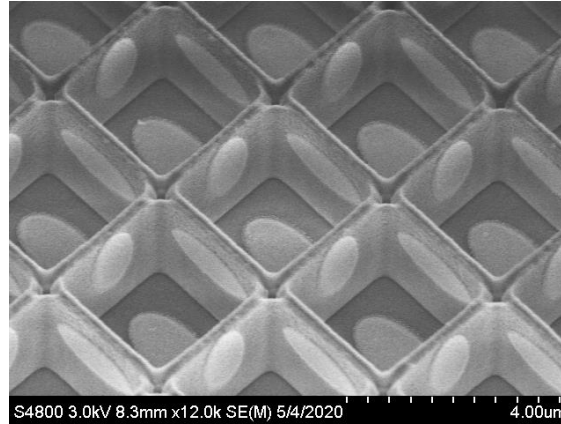
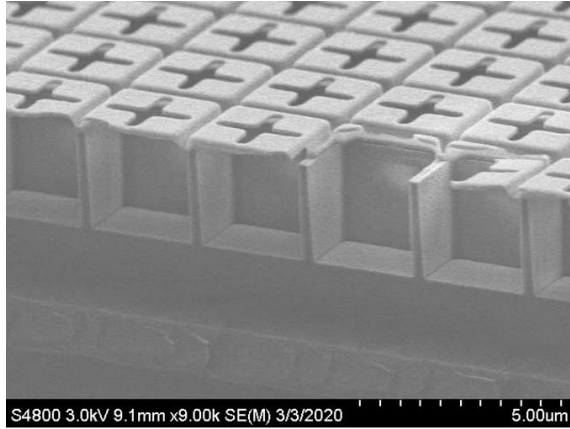


Membrane Projection Lithography (MPL)





Fabricated MPL structures

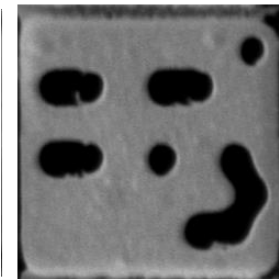
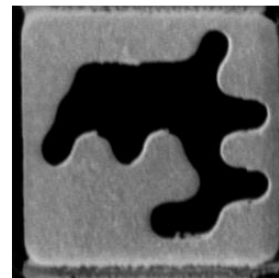
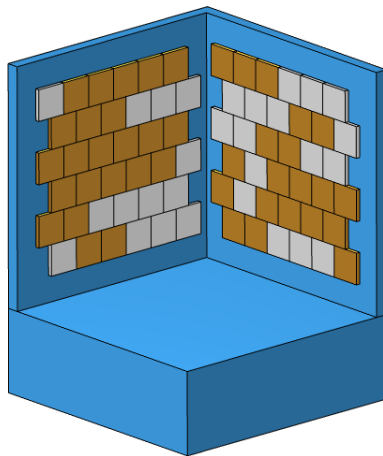
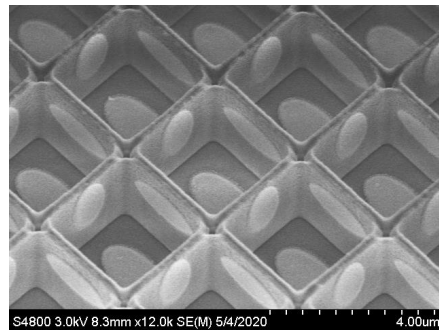
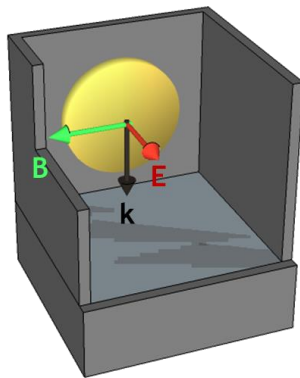


- Material can be deposited on the walls or the floor of structures
- Multiple depositions are possible
- Heterogeneous cells can be fabricated



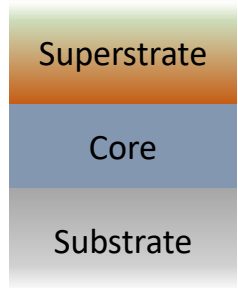
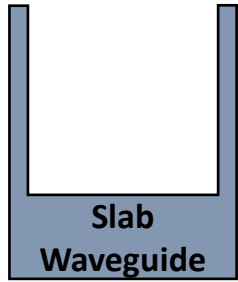
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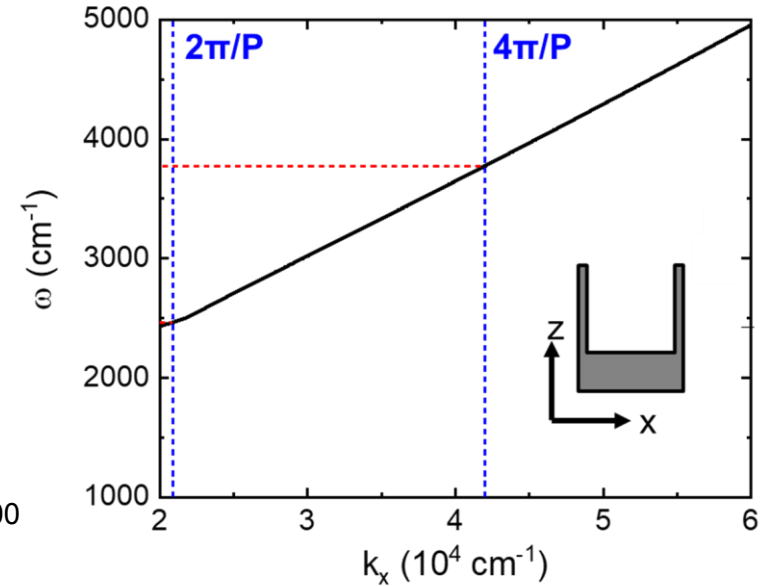
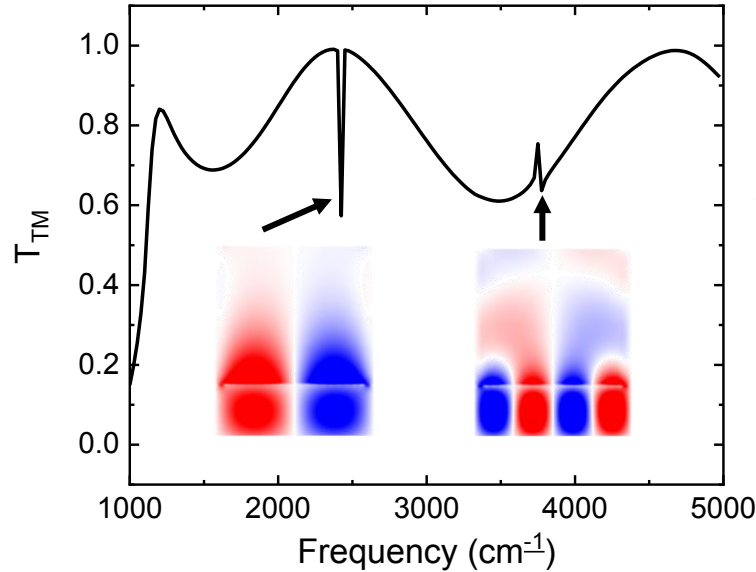




Empty Box Response



Quasi-2D Structure



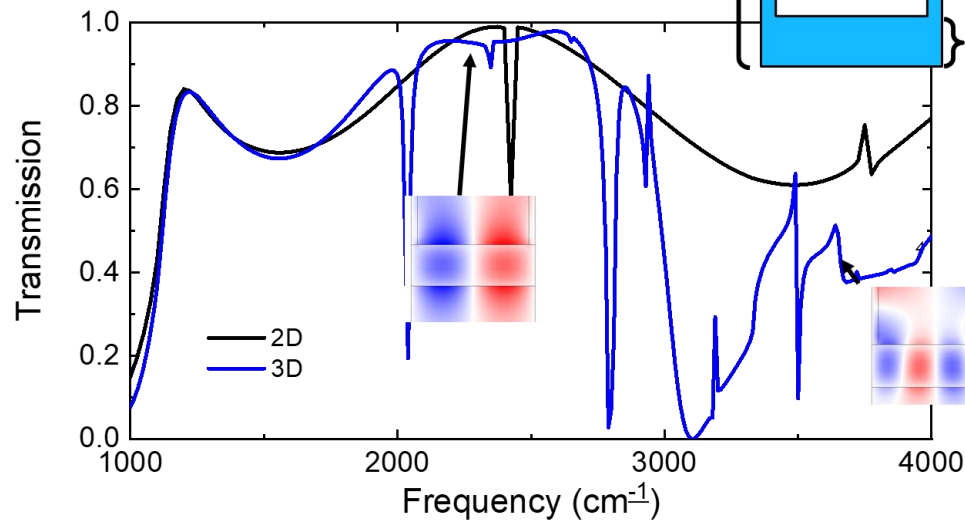
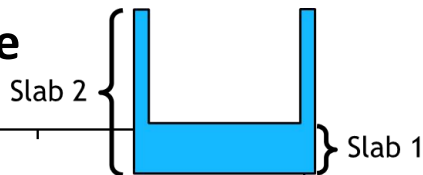
Sharp resonances from slab waveguide atop broad Fabry-Perot oscillations





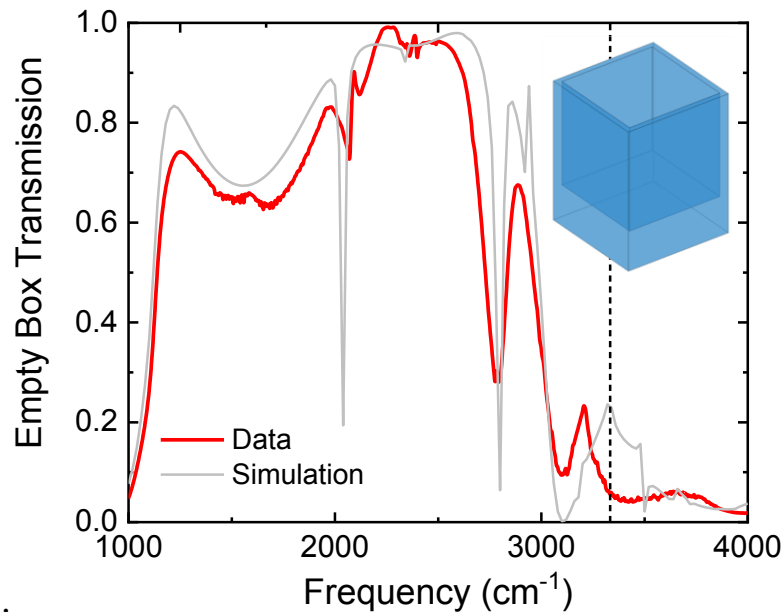
Empty Box Response

2D Structure



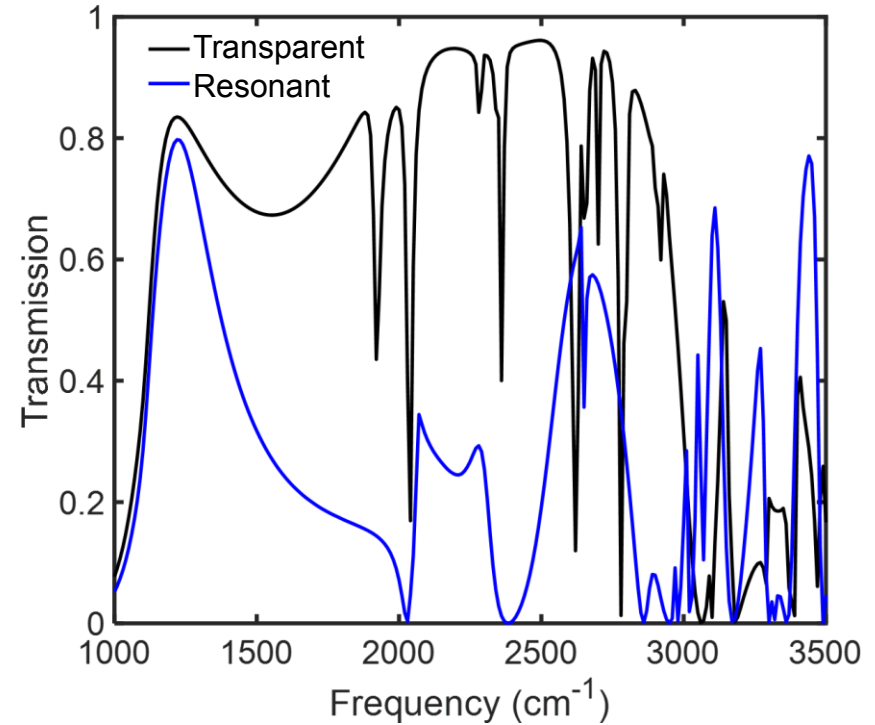
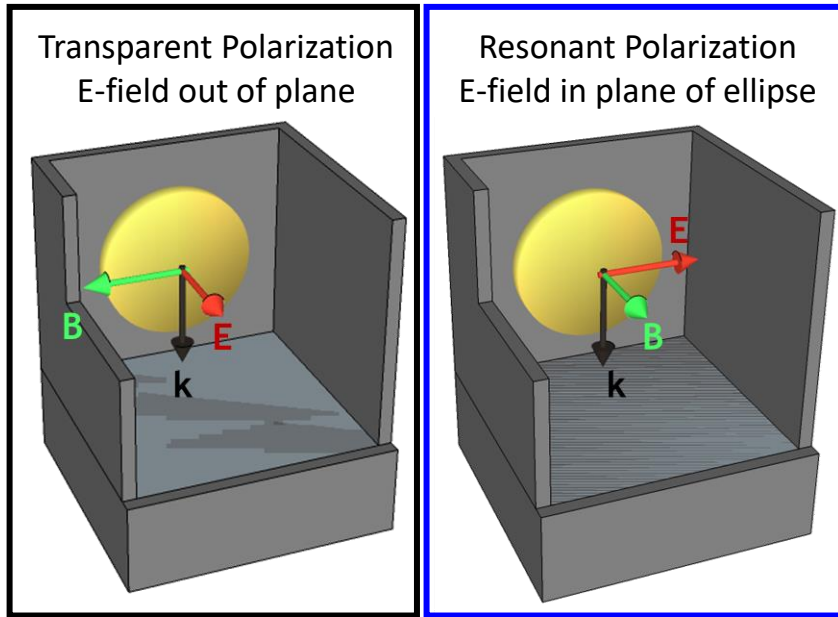
- Multiple “slabs” in 3D structure complicate response
- Fabricated structures show good agreement with modeling.

3D Structure





Elliptical Inclusions

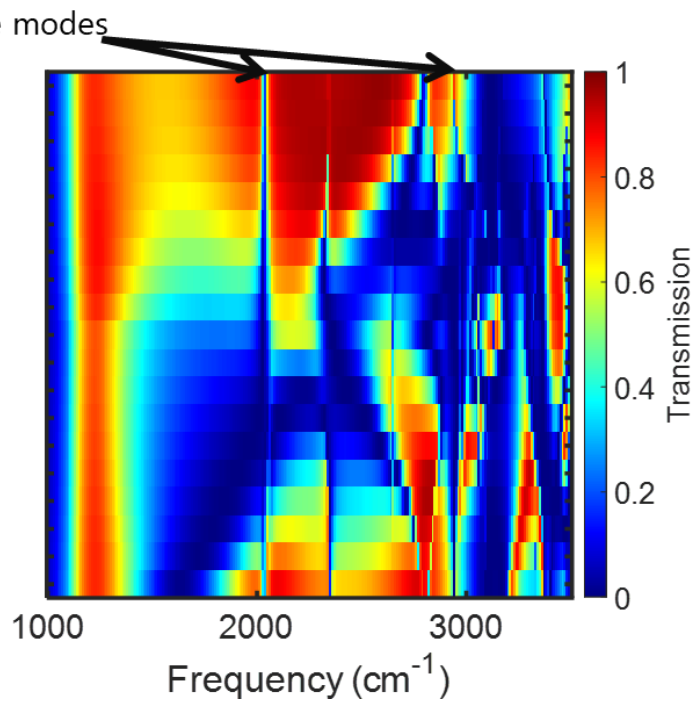
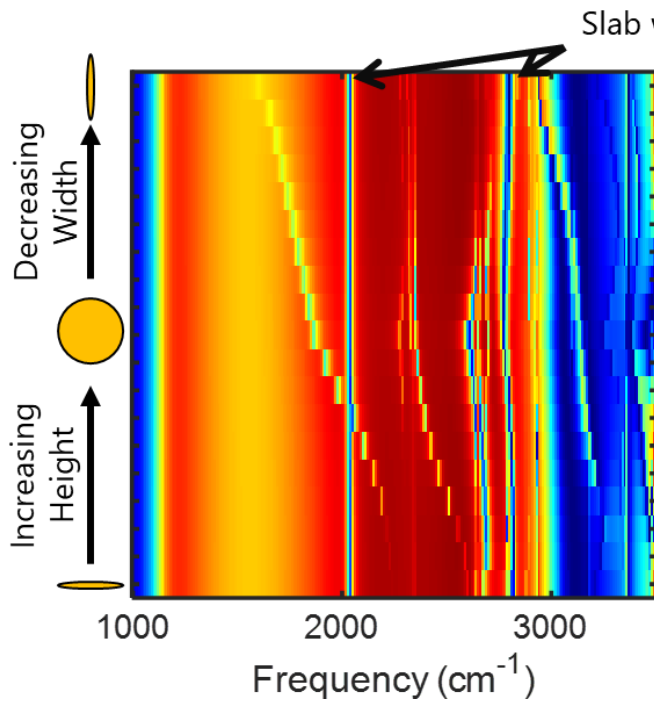




Ellipse response

Transparent Polarization

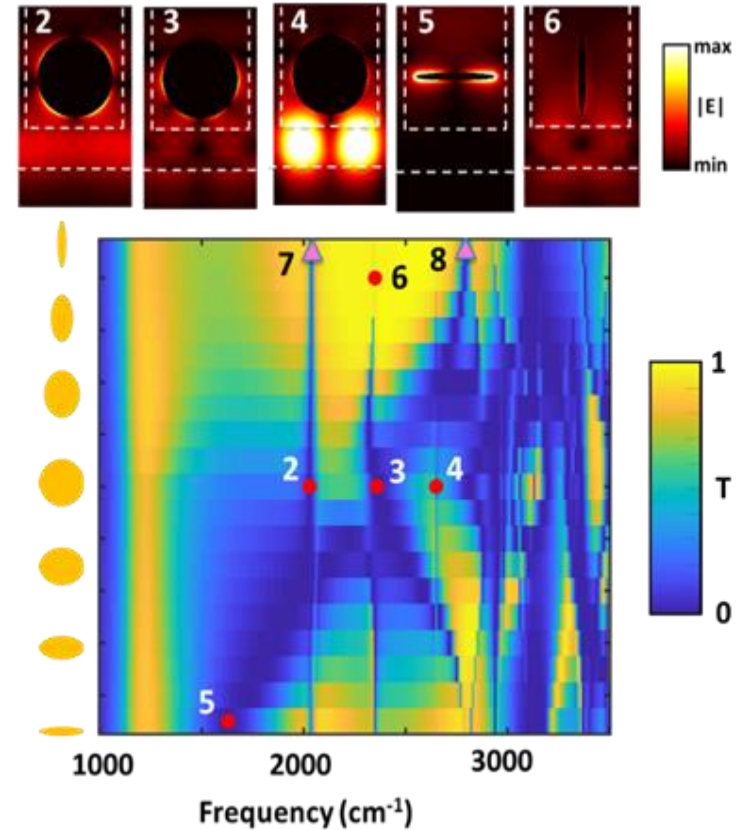
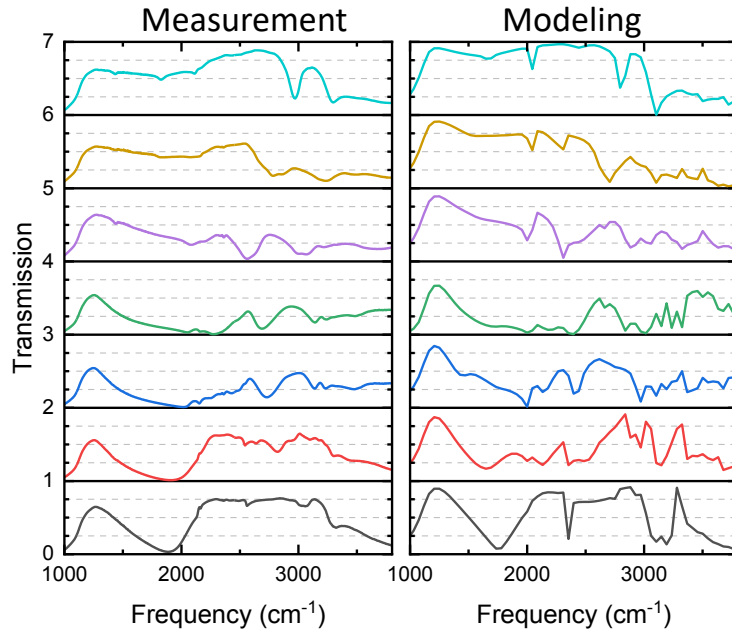
Resonant Polarization





Measured Ellipse Response

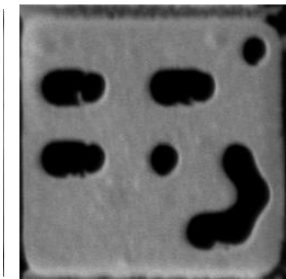
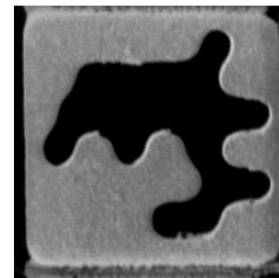
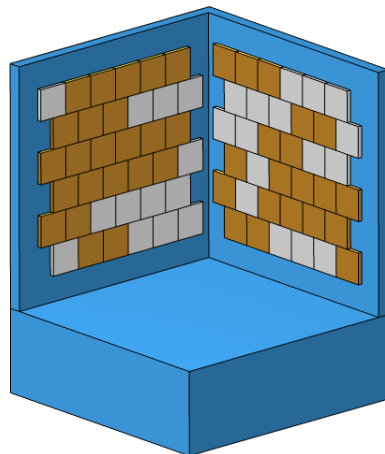
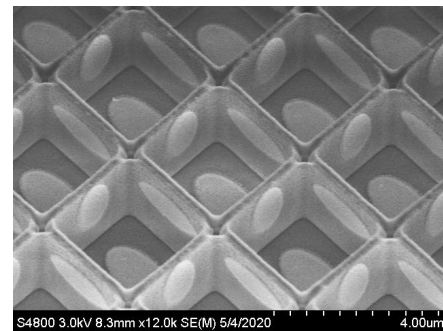
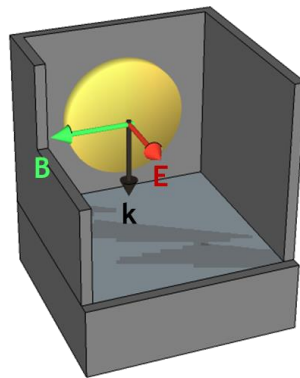
Response dominated by ellipse resonances coupled to slab waveguide modes





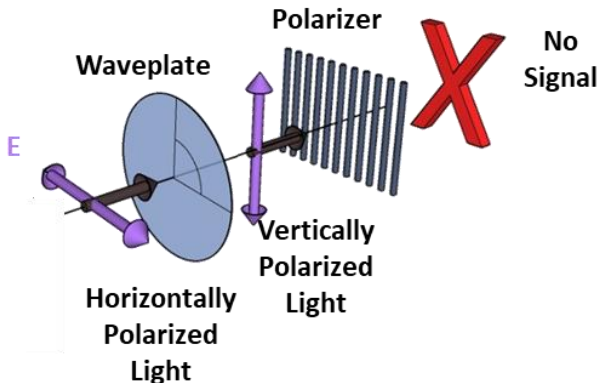
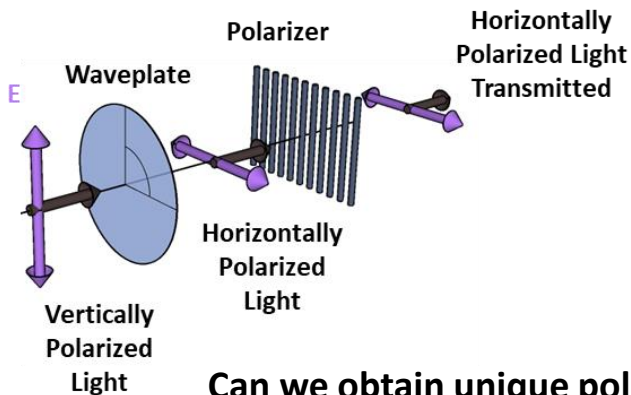
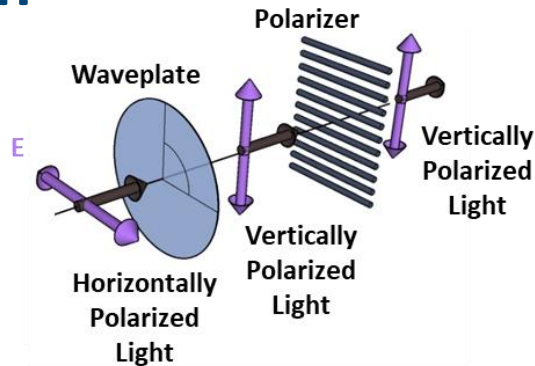
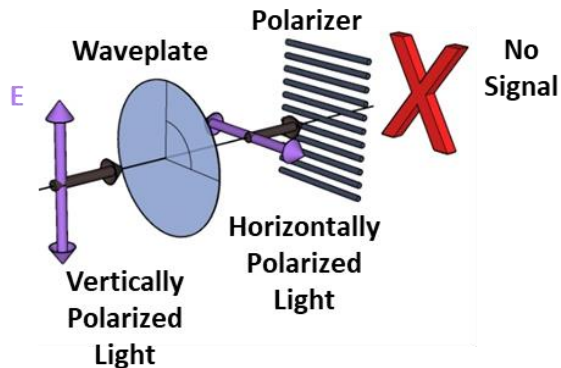
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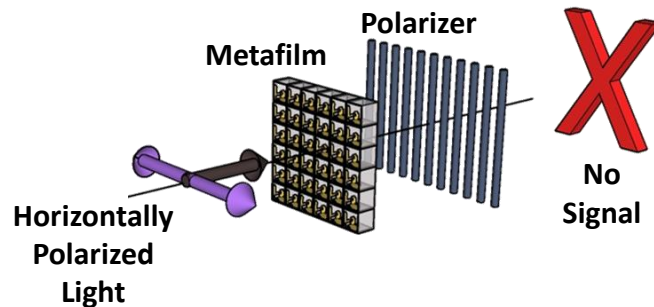
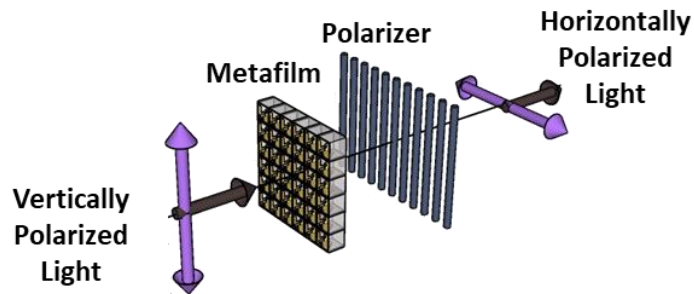
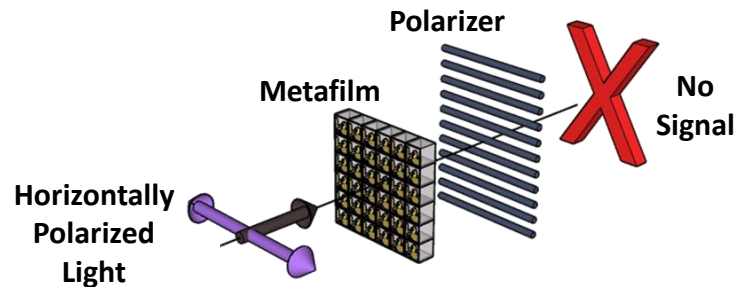
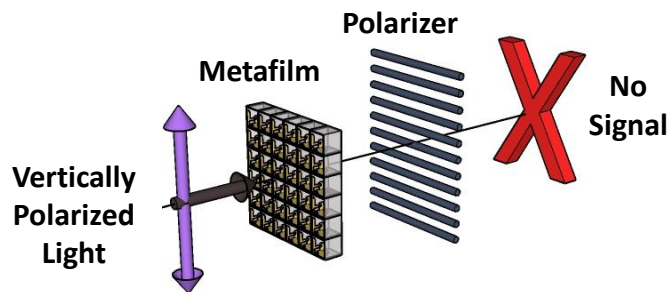
Conventional Polarization Rotation



Can we obtain unique polarization response via on-wall anisotropy?



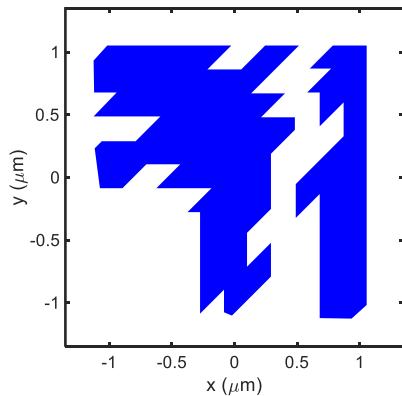
Asymmetric Transmission Metasurface



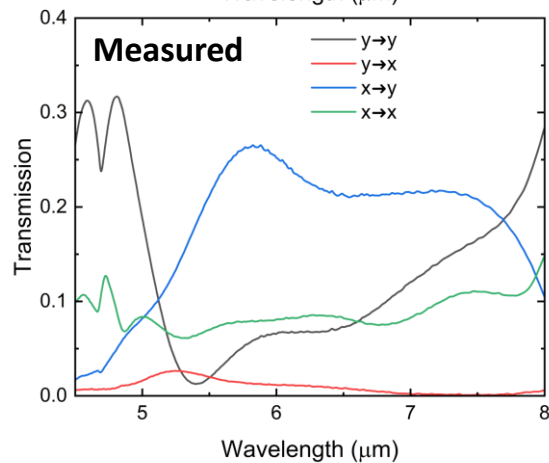
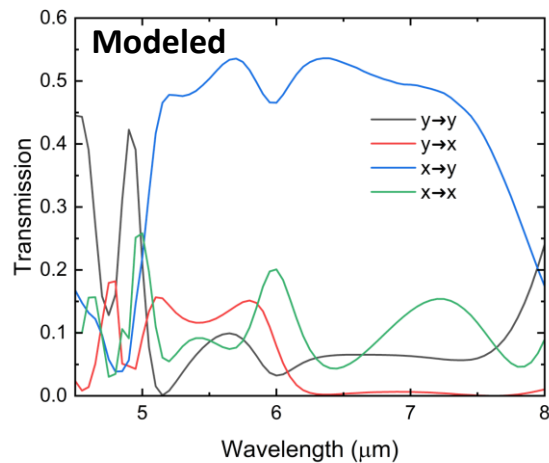
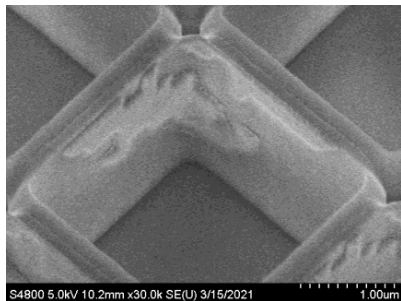
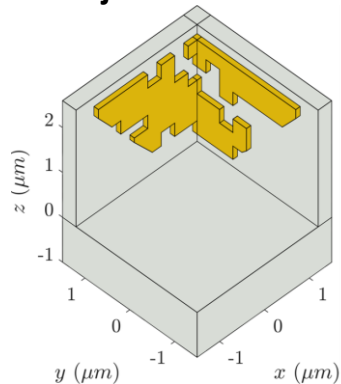


Asymmetric Transmission

Membrane Pattern



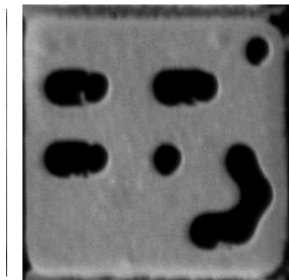
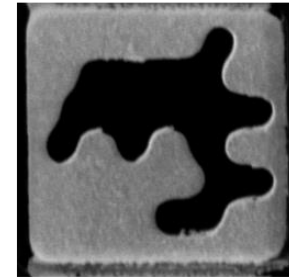
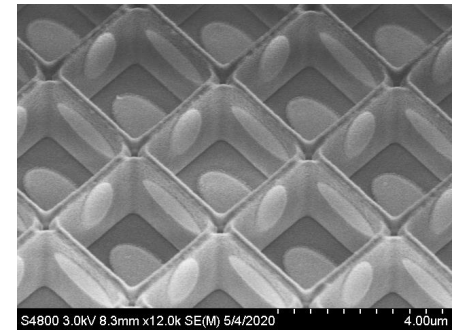
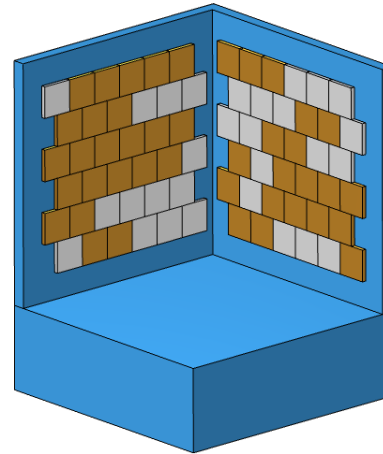
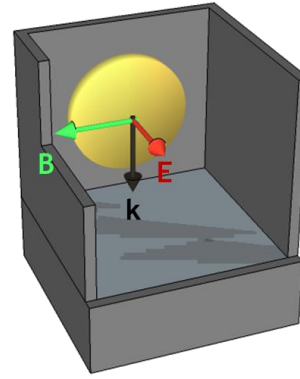
Projected Pattern





Outline

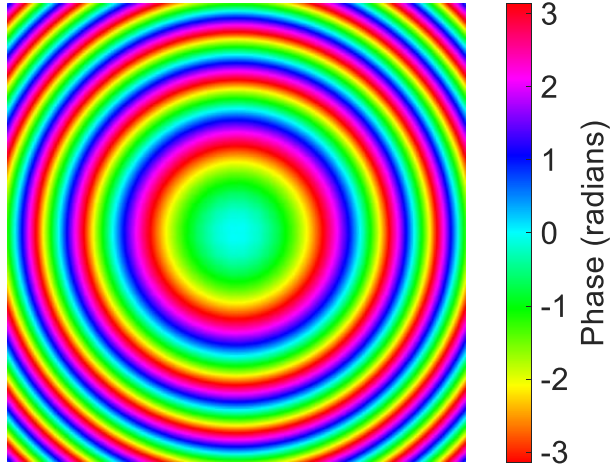
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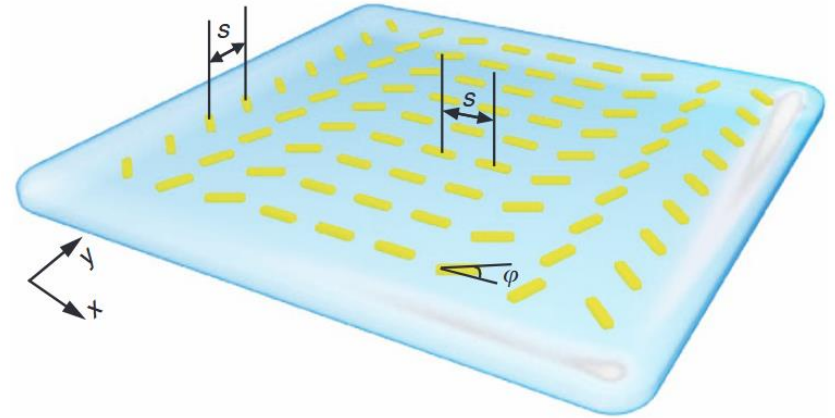
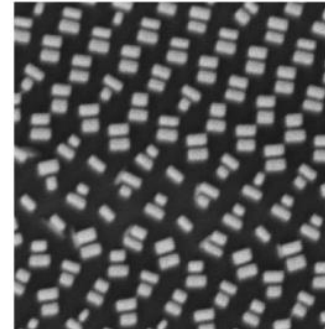


Metalens

$$\phi_{\text{lens}} = -\frac{2\pi}{\lambda} \sqrt{r^2 + f^2} - f$$



Focusing from flat optics via designed transmission phase.

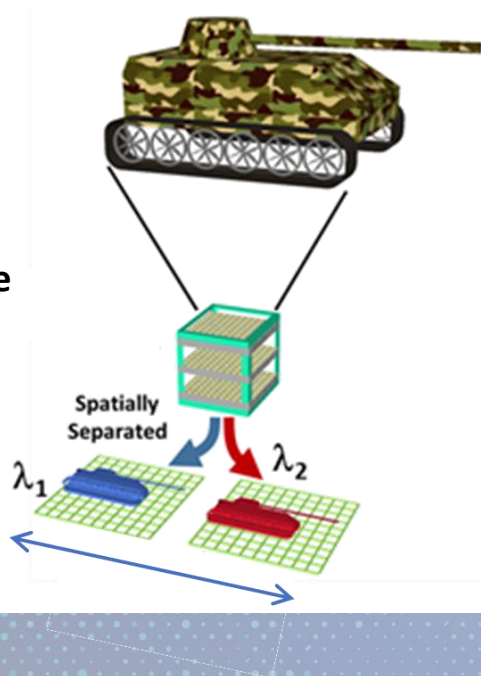




Polarization Indexed Metalens

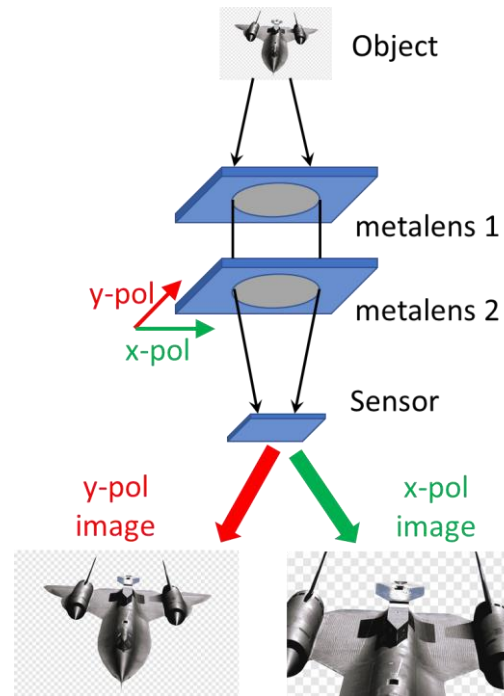
Two-Color Shared Aperture Lens

Single Surface
Two color
10 mm clear aperture
Polarization-indexed
f/2.5 lens



Two-Position Zoom Imager

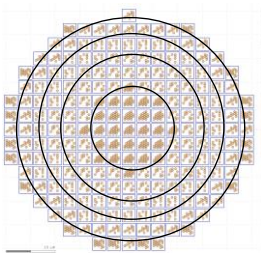
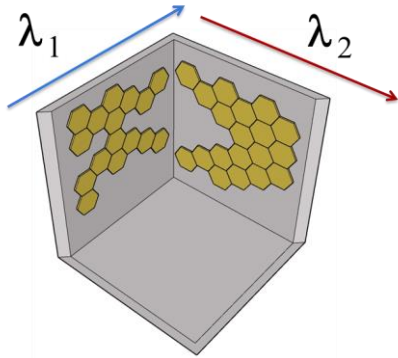
2 Surfaces
Single color
3 mm clear aperture
Polarization-indexed
2 magnifications





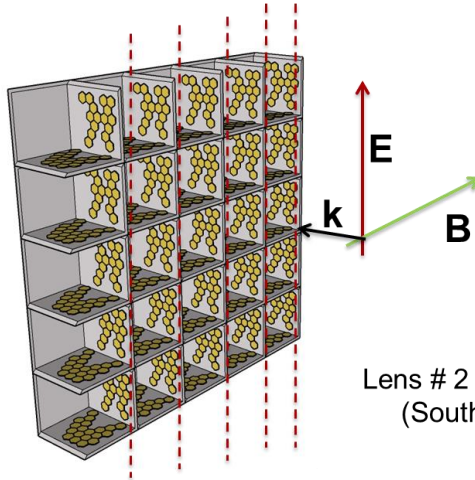
MPL-enabled schematic

Functionality Enabled at the
Unit Cell Level

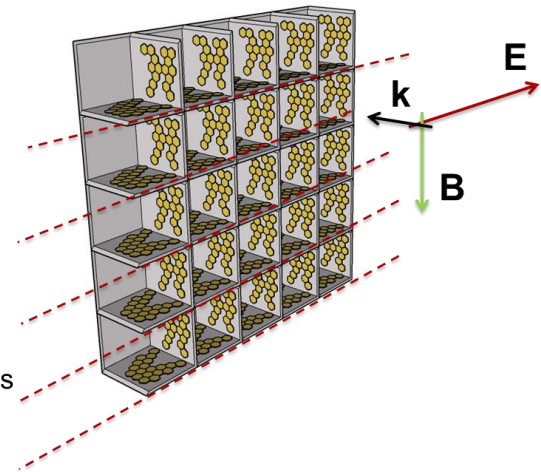


Lens created by
populating
aperture with
phase elements

Lens # 1 Elements
(East Wall)



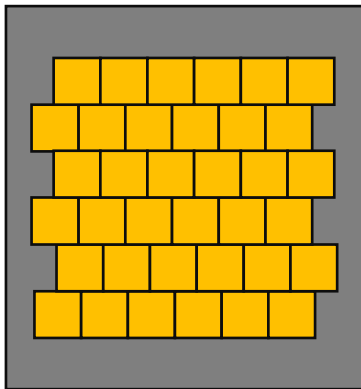
Lens # 2 Elements
(South Wall)





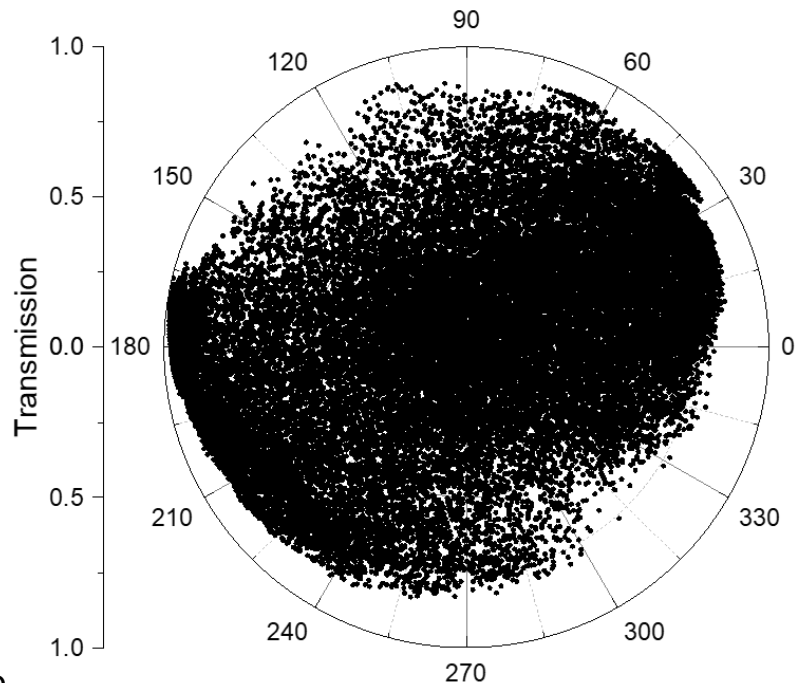
Phase element design

Design Space



1. Determine phase bins
2. Pixelate wall into gold elements (squares, hexagons...)
3. Optimize for desired phase with large transmittance by selecting between gold and air for each pixel.

Phase Map for All Simulated Elements at $4\ \mu\text{m}$

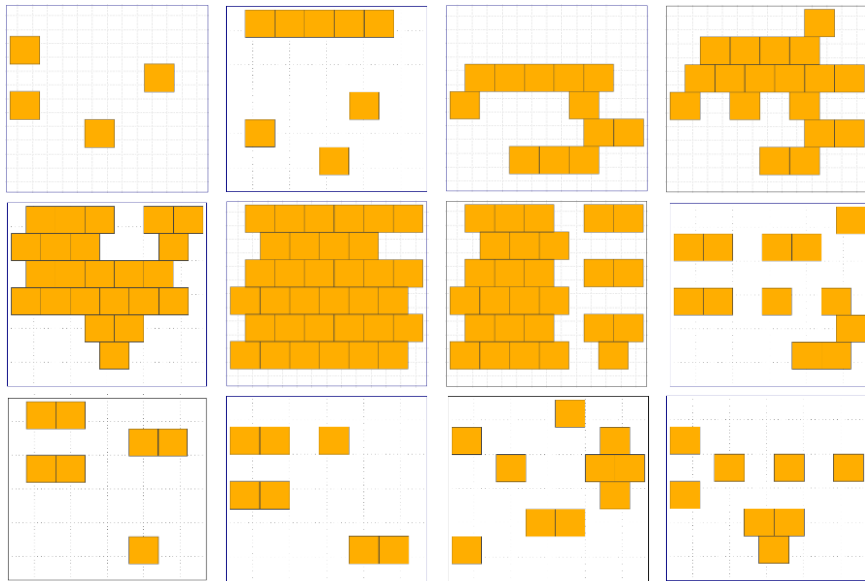


>80000 simulated structures

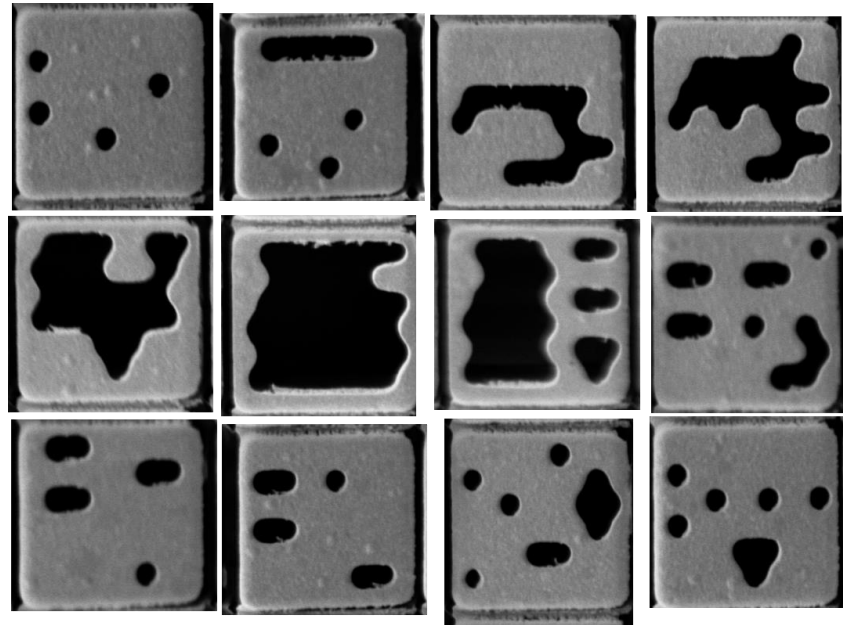


Brick-Like element design

Design Phase Elements



Patterned Membranes

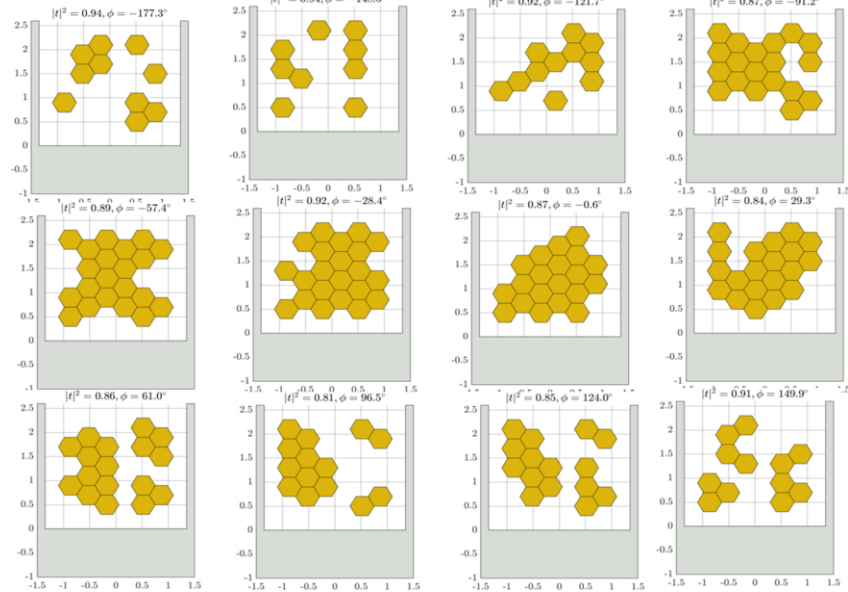


- Designed for transmission phase of 0° to 330° in 30° increments.
- Transmission for all elements is $>65\%$.

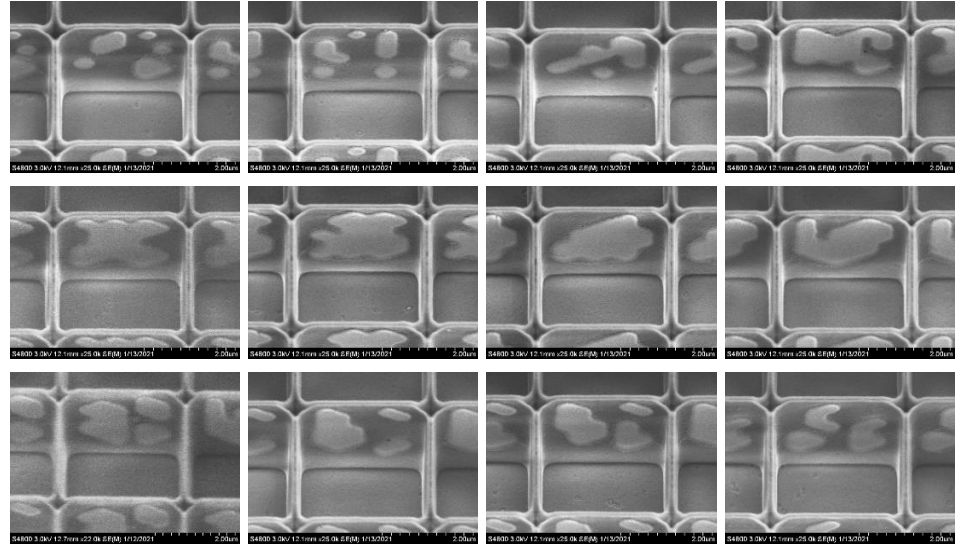


Hexagonal Pixel design

Design Phase Elements



Patterned Membranes

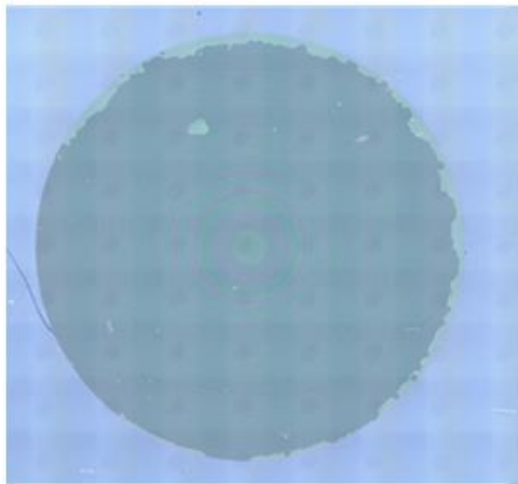


- Designed for transmission phase of 0° to 330° in 30° increments.
- Transmission for all elements is $>80\%$.



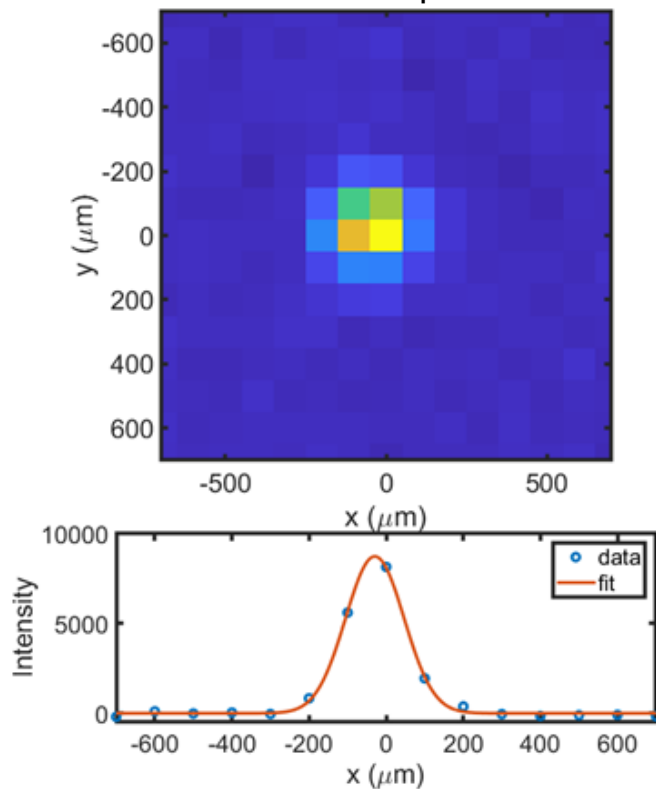
Initial Lens Characterization

Lens Optical Image



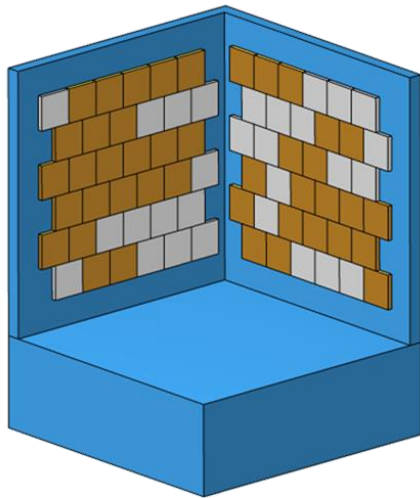
- Initial characterization shows focusing to ~ 350 μm spot.
- Further characterization underway to evaluate performance with optimized detection system.

Focal Spot

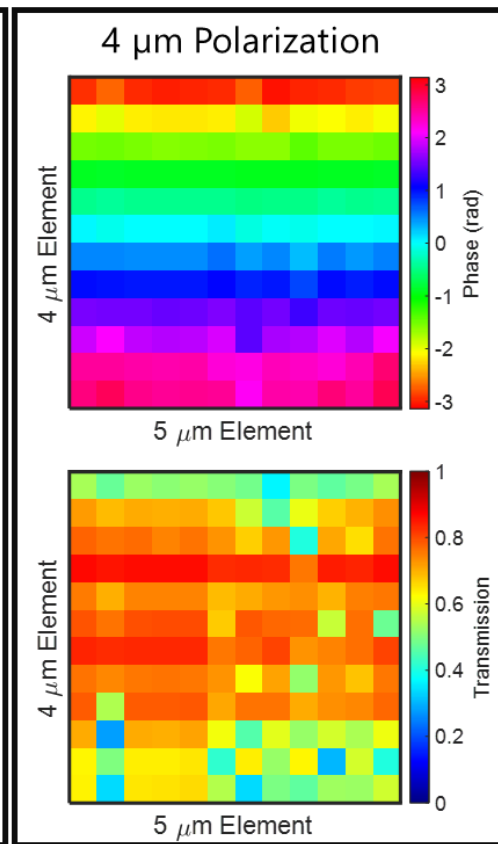
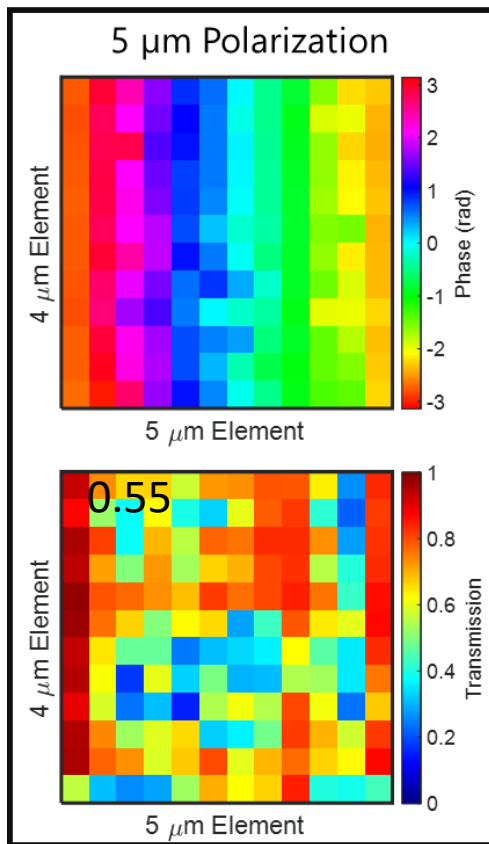




Interwall Interaction



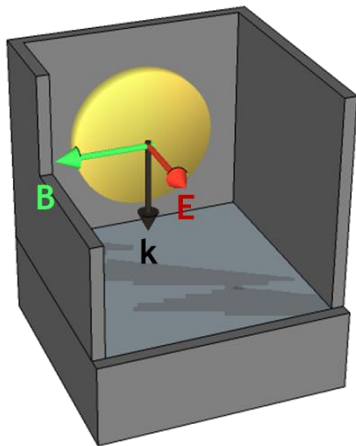
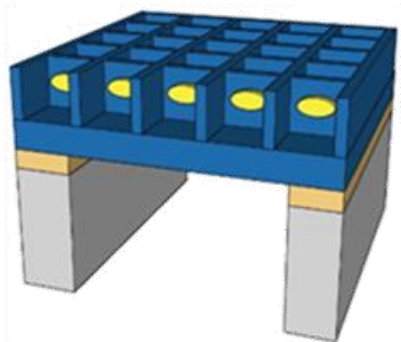
- Phase behavior nearly unchanged
- Transmission amplitude decreased for certain combinations





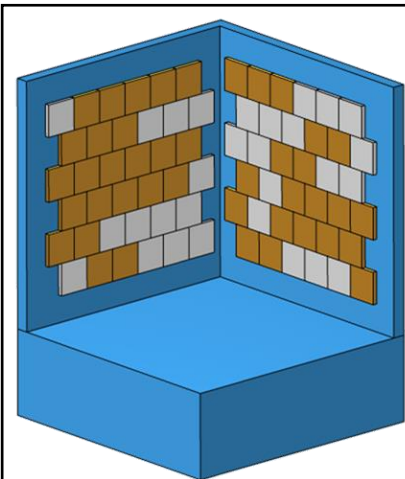
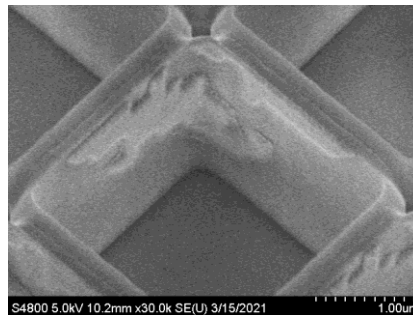
Summary

Membrane Projection Lithography



Vertically Oriented Ellipses

Asymmetric Transmission



Multi-function Metalenses

