



# IEEE RESEARCH AND APPLICATIONS OF PHOTONICS IN DEFENSE

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## Plasmonic Response in Three- Dimensional Meta-Films

*Michael Goldflam<sup>1</sup>, Katherine Musick<sup>1</sup>, Paul Resnick<sup>1</sup>, Eric Whiting<sup>2</sup>, Sawyer Campbell<sup>2</sup>, Lei Kang<sup>2</sup>, Michael Sinclair<sup>1</sup>, Douglas Werner<sup>2</sup>, D. Bruce Burkel<sup>1</sup>*

*1) Sandia National Laboratories, 2) Penn State University*



August 4, 2021

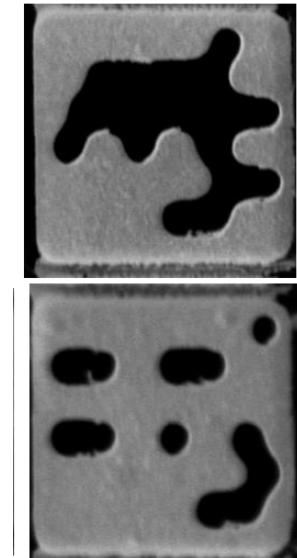
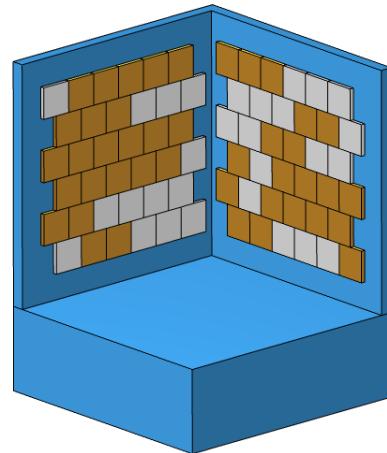
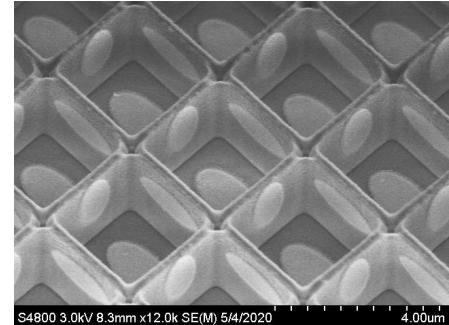
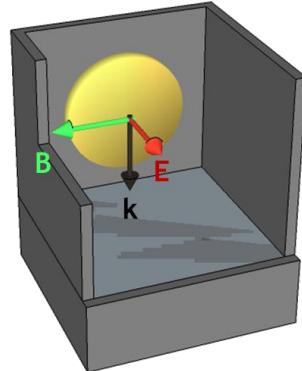
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# Outline

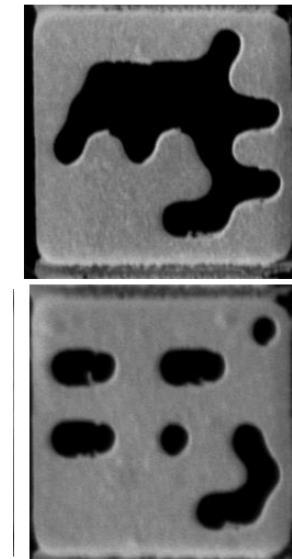
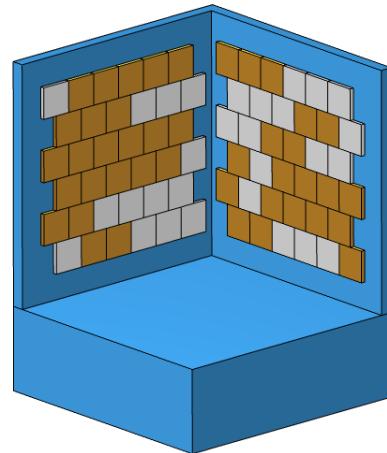
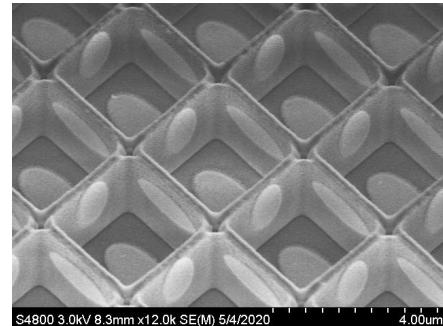
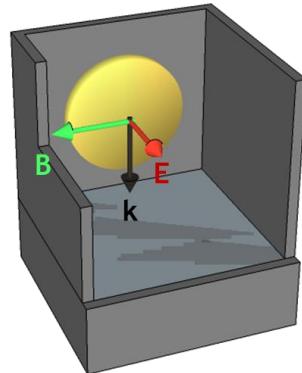
- Why three-dimensional?
- Membrane Projection Lithography
- Vertically oriented ellipses
- Asymmetric transmission
- Multifunction metlenses
  - Single Color
  - Two Color





# Outline

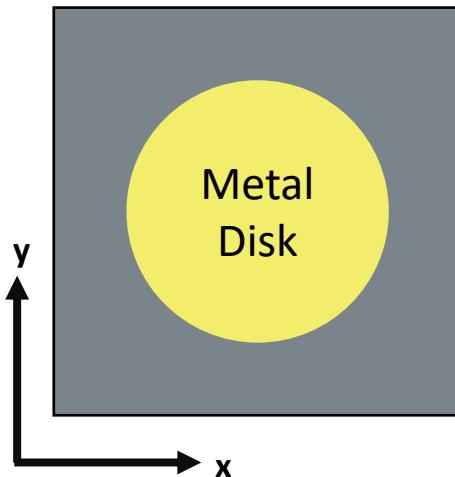
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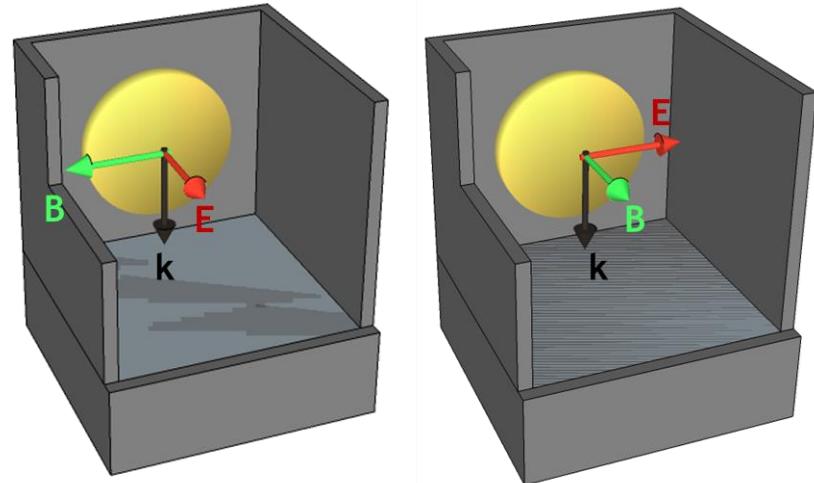
# Why three-dimensional?

Planar Metasurface



- Metal disk for electric field along x or y

Three-Dimensional Metasurface

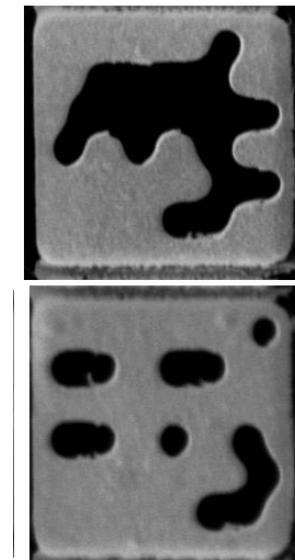
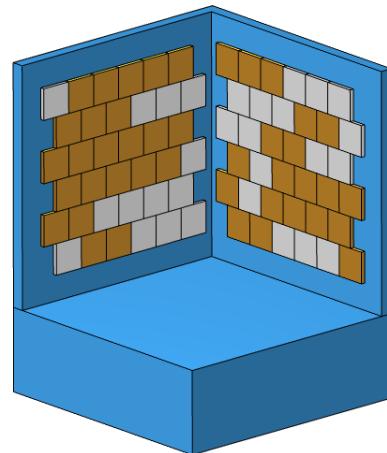
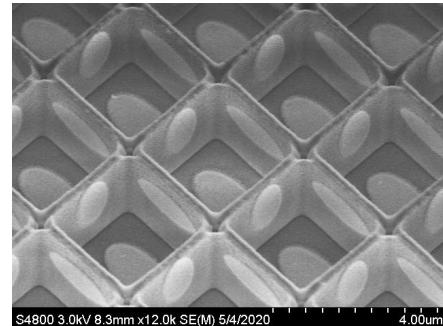
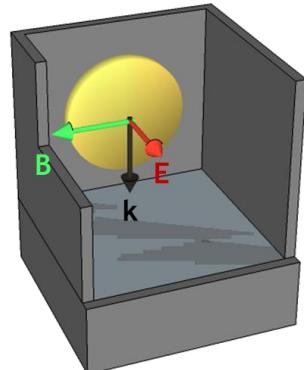


- Metal disk excited for one polarization and transparent for the other
- Decoupled polarization-indexed response



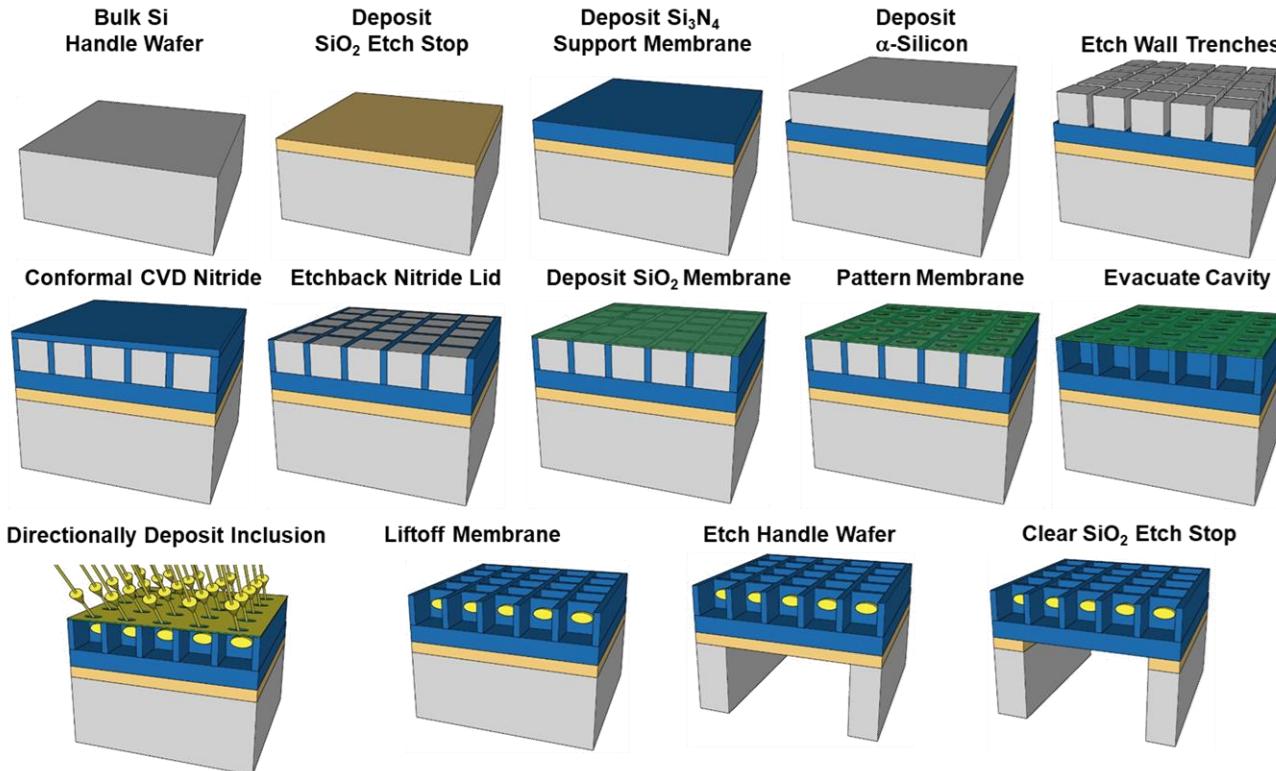
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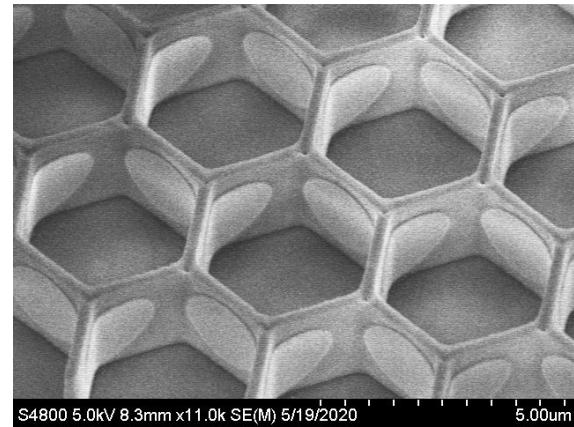
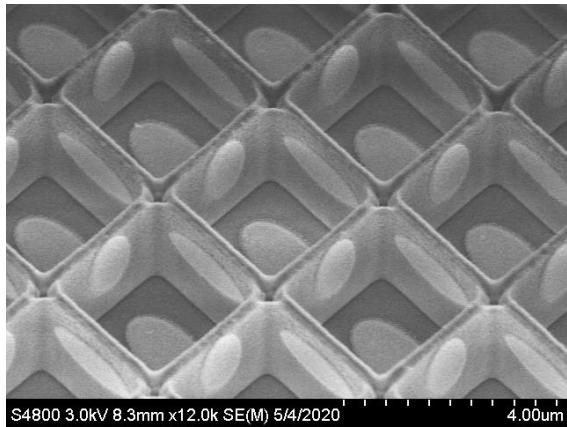
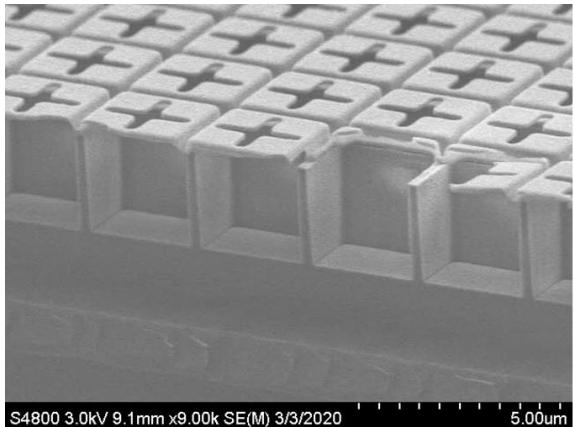


# Membrane Projection Lithography (MPL)





# Fabricated MPL structures

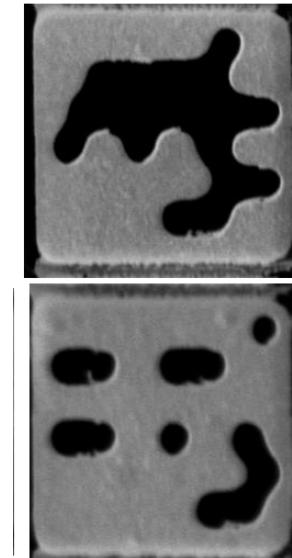
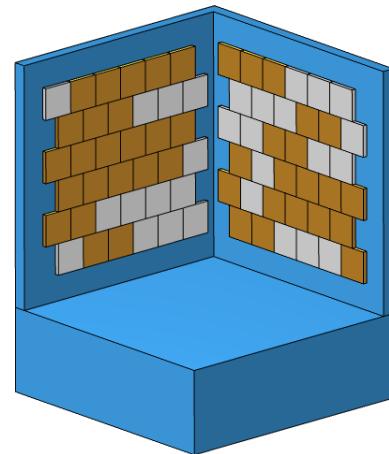
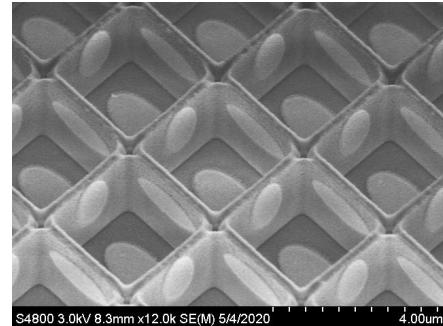
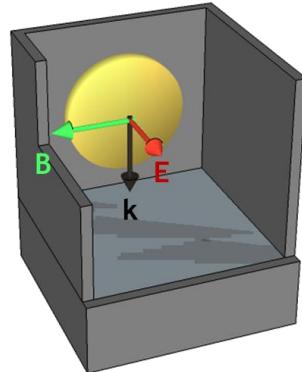


- Material can be deposited on the walls or the floor of structures
- Multiple depositions are possible
- Heterogeneous cells can be fabricated



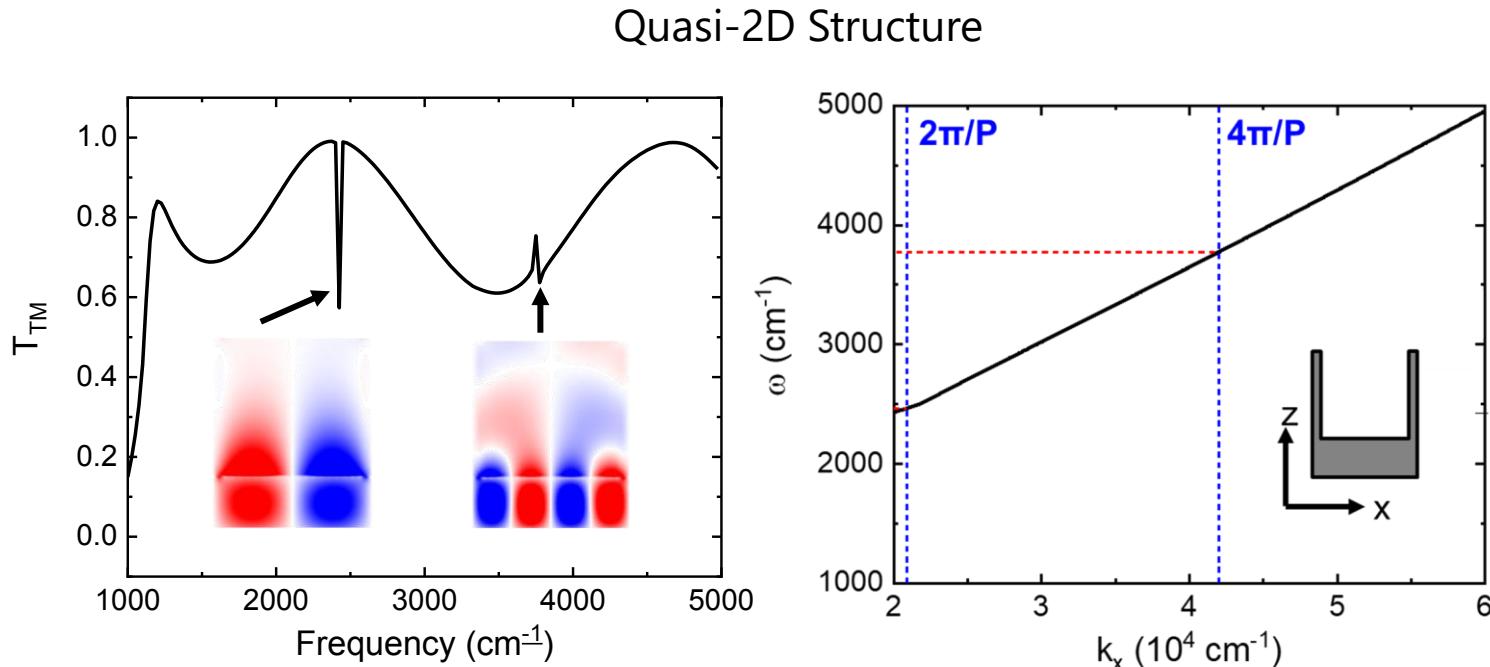
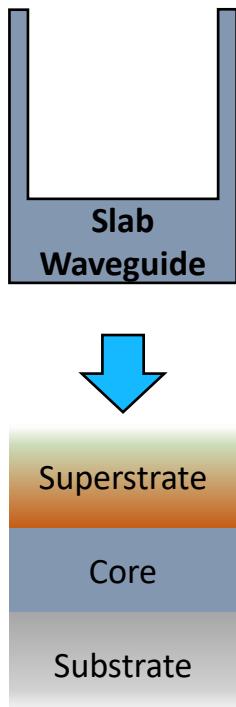
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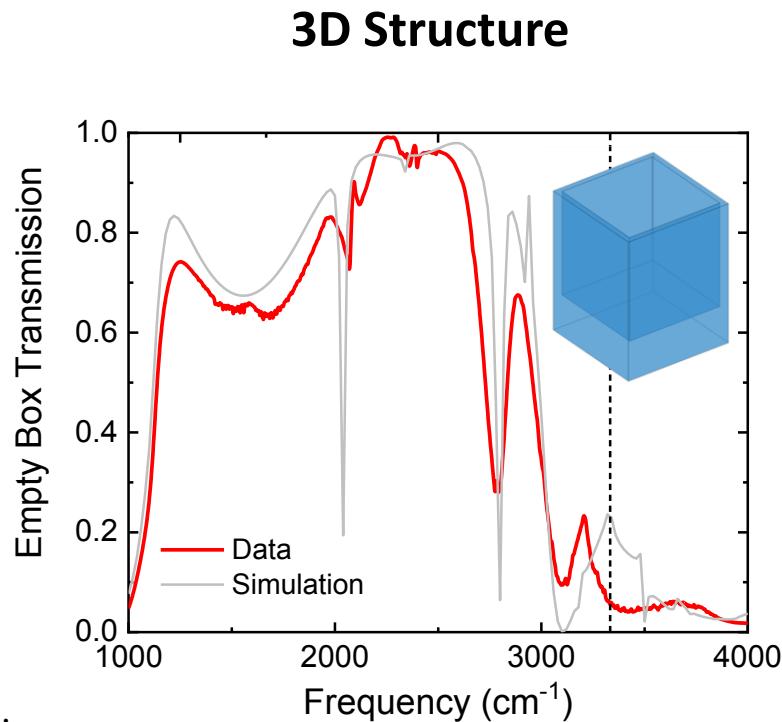
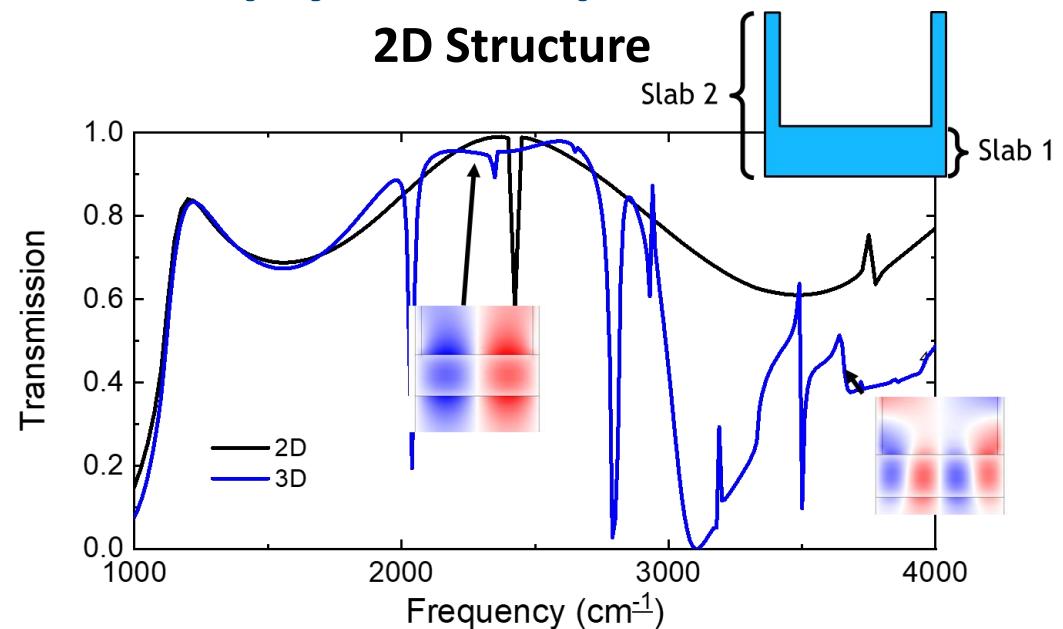
# Empty Box Response



Sharp resonances from slab waveguide atop broad Fabry-Perot oscillations



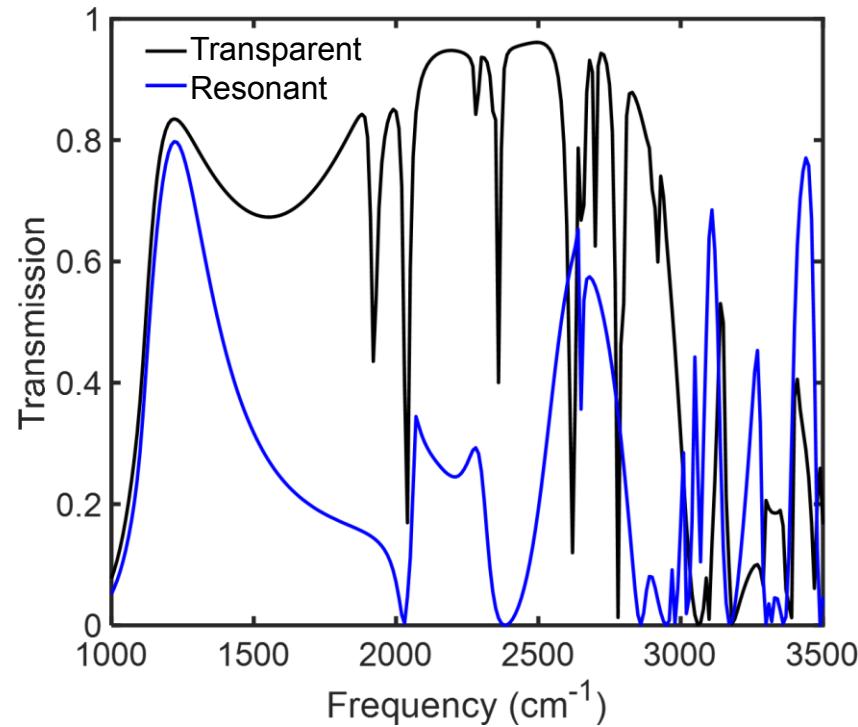
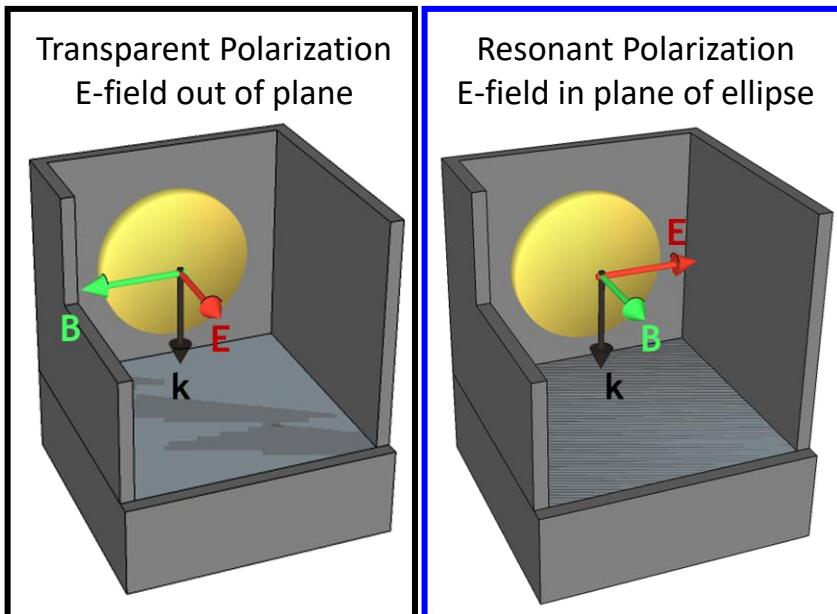
# Empty Box Response



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



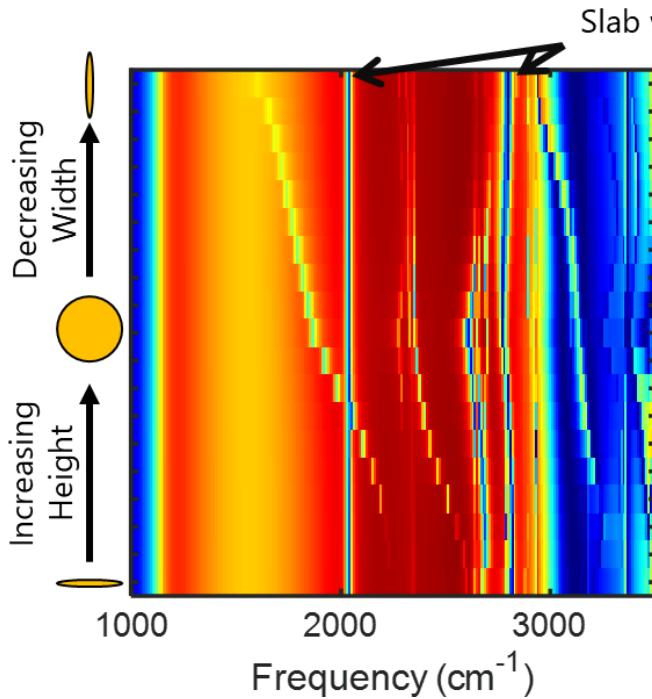
# Elliptical Inclusions



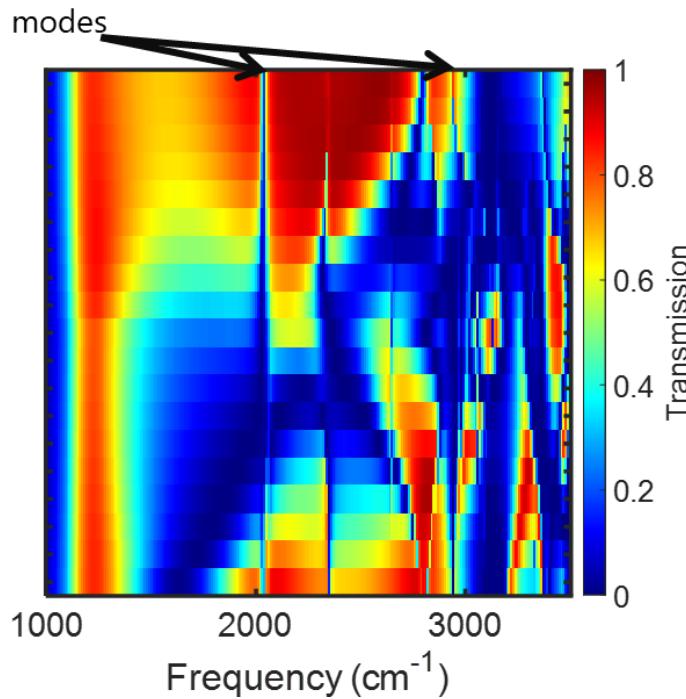


# Ellipse response

Transparent Polarization



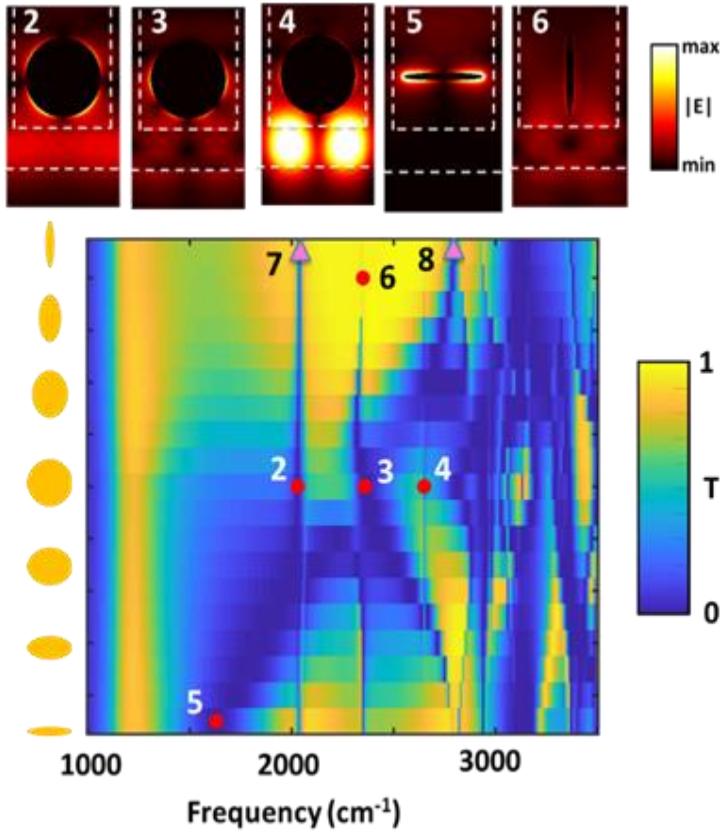
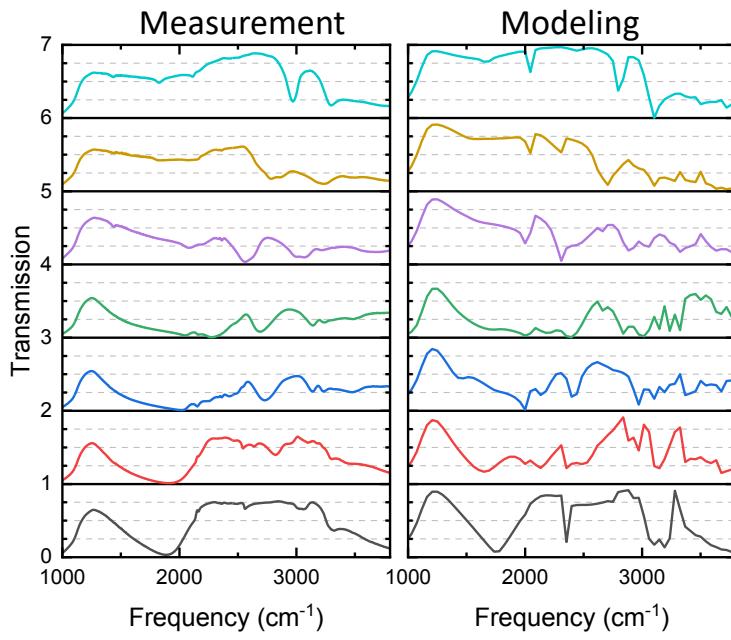
Resonant Polarization





# Measured Ellipse Response

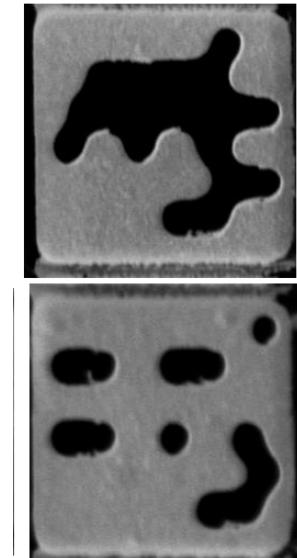
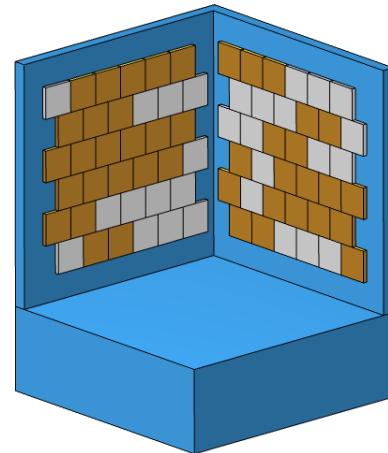
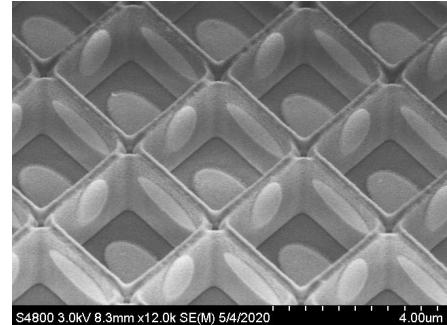
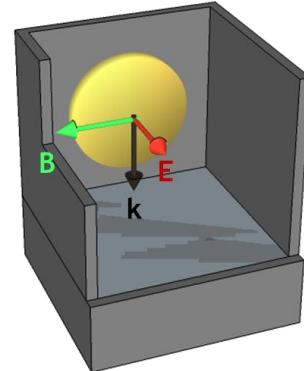
Response dominated by ellipse resonances coupled to slab waveguide modes





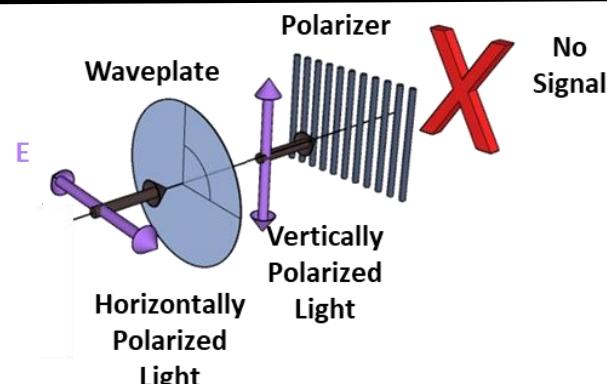
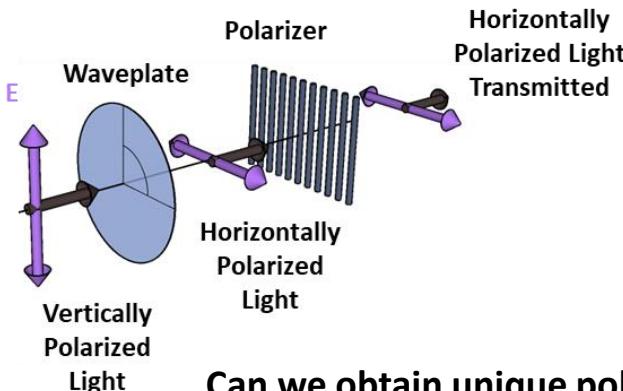
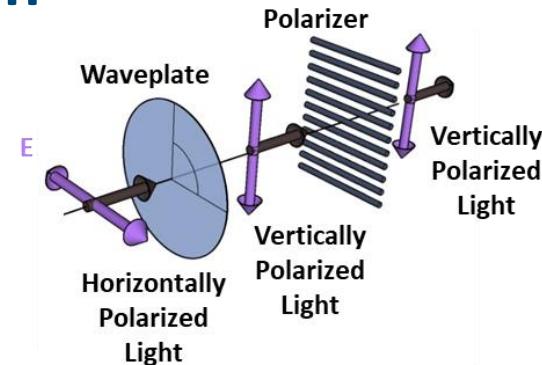
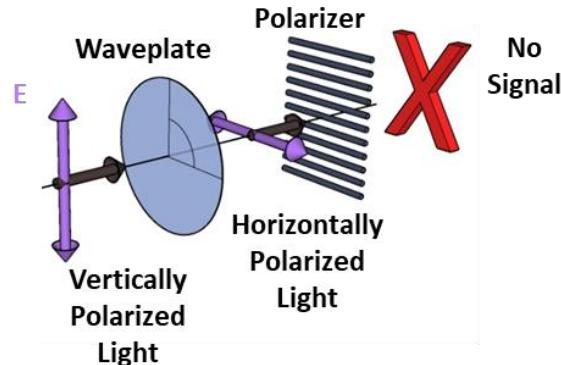
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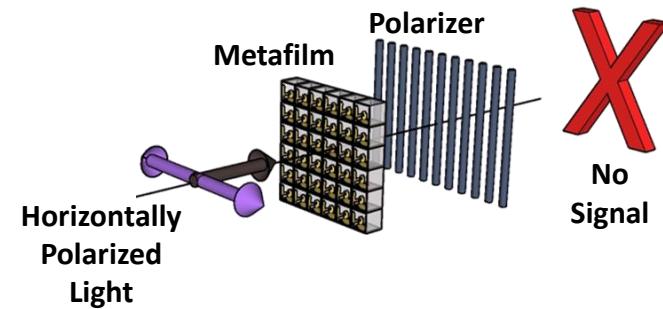
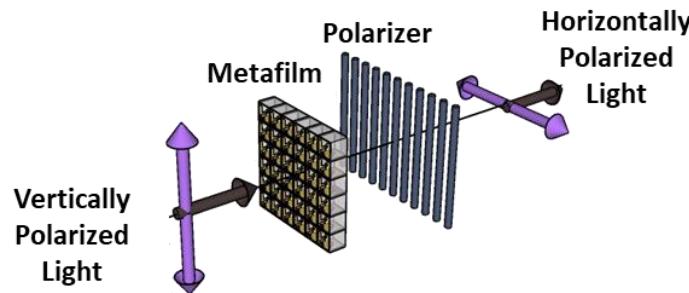
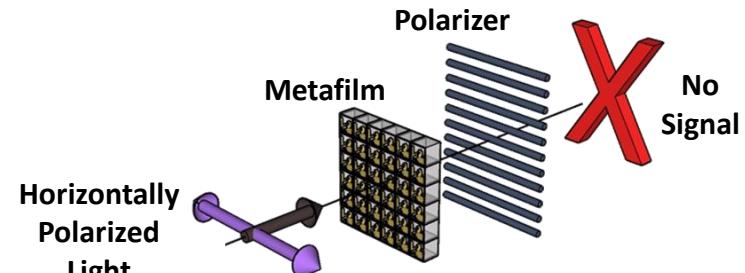
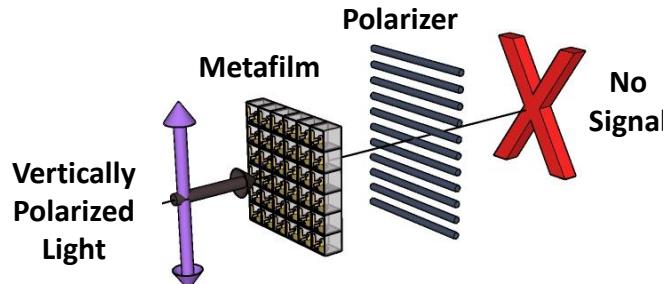
# Conventional Polarization Rotation



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



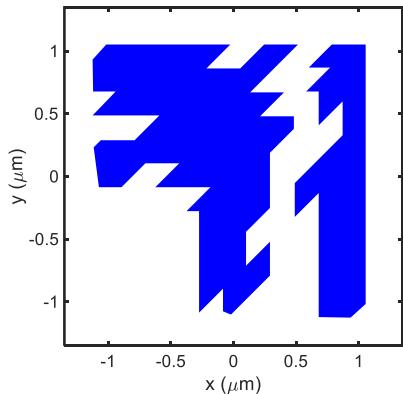
# Asymmetric Transmission Metasurface



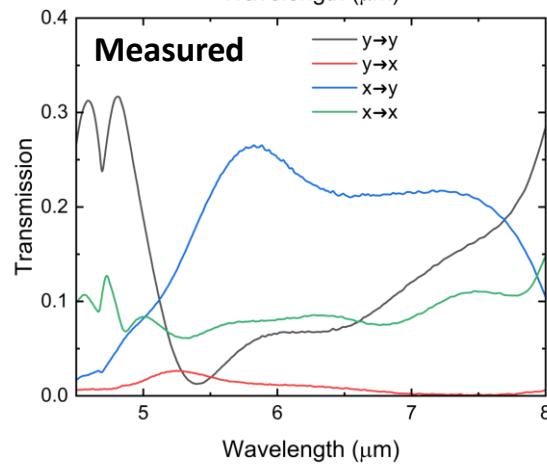
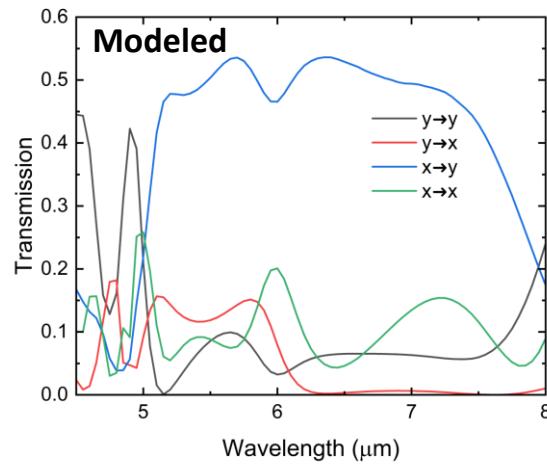
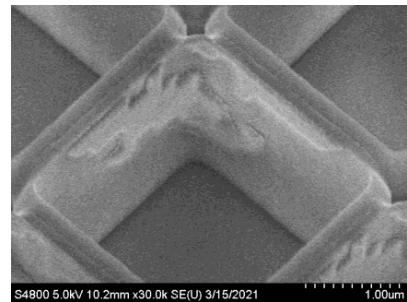
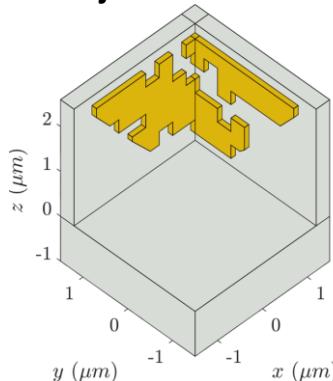


# Asymmetric Transmission

Membrane Pattern



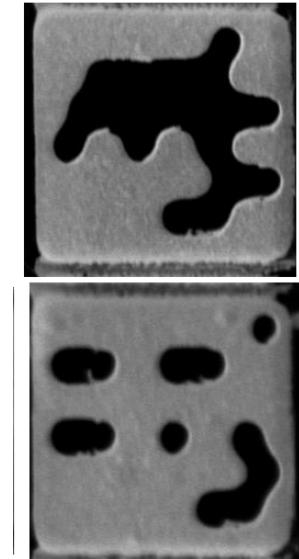
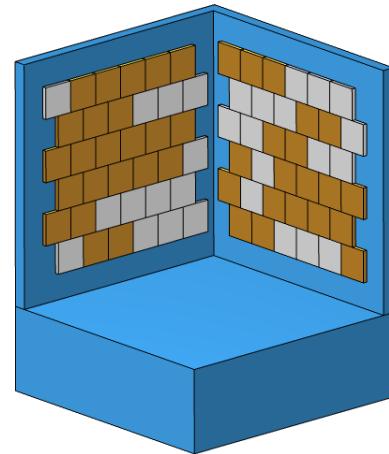
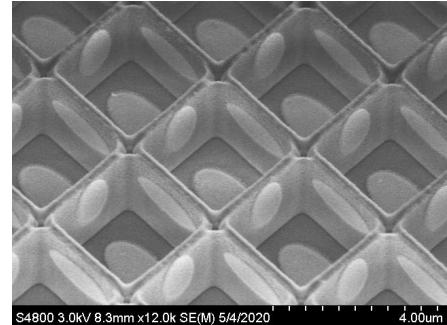
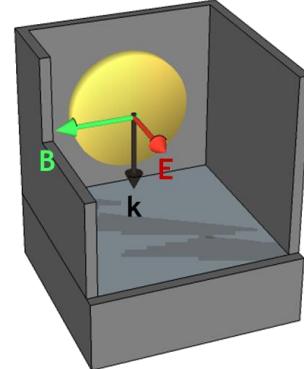
Projected Pattern





# Outline

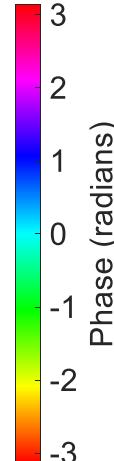
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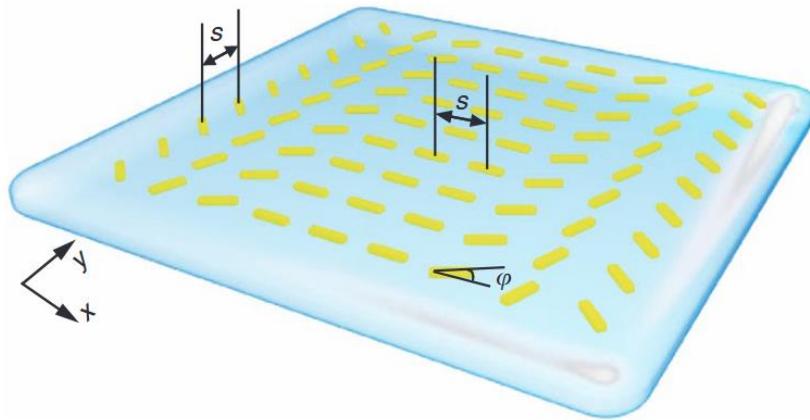


# Metalens

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



Focusing from flat optics via designed transmission phase.



X. Chen, et al., Nat Commun, (2012), DOI: 10.1038/ncomms2207.

W. T. Chen, et al., Nat Nanotechnol, (2018), DOI: 10.1038/s41565-017-0034-6.

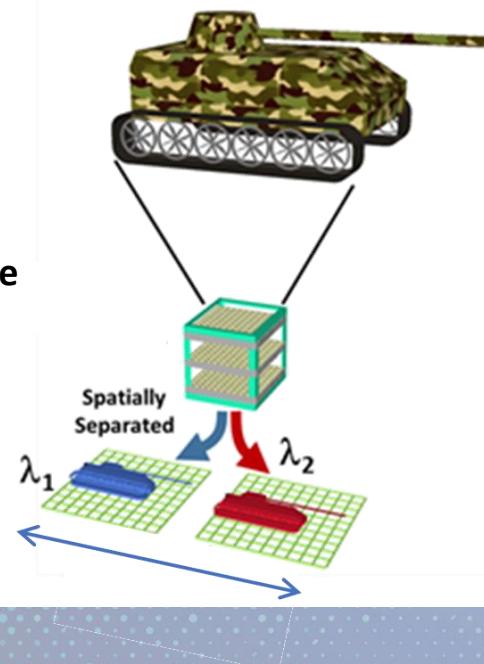
J. Engelberg, et al., Nat Commun, (2020), DOI: 10.1038/s41467-020-15972-9.



# Polarization Indexed Metalens

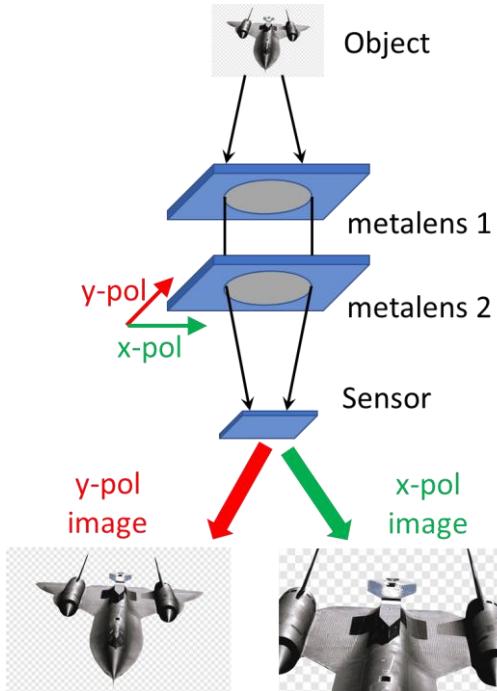
## Two-Color Shared Aperture Lens

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



## Two-Position Zoom Imager

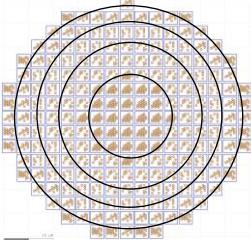
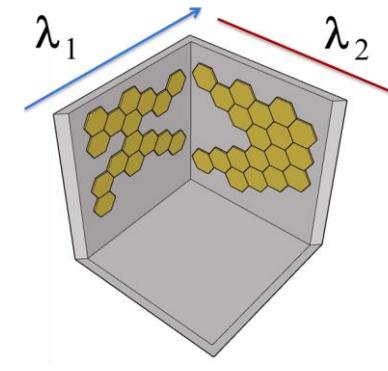
2 Surfaces  
Single color  
3 mm clear aperture  
Polarization-indexed  
2 magnifications





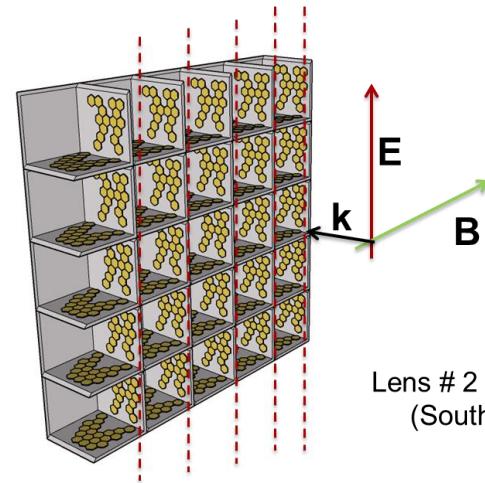
# MPL-enabled schematic

## Functionality Enabled at the Unit Cell Level

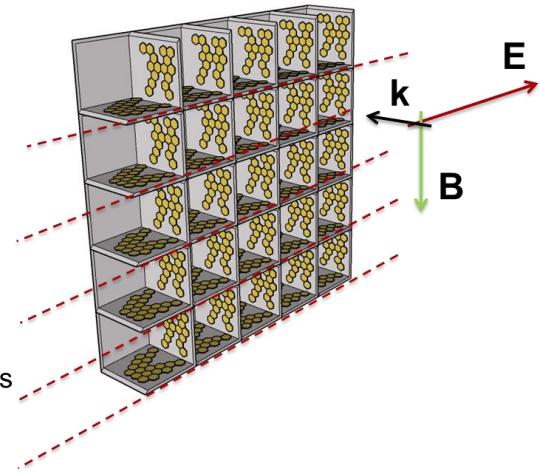


**Lens created by populating aperture with phase elements**

Lens # 1 Elements  
(East Wall)



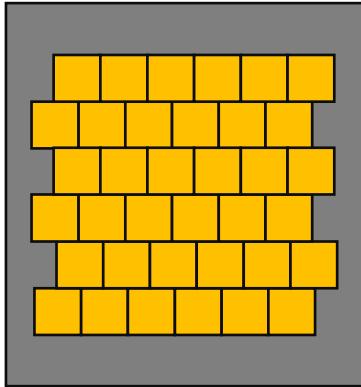
Lens # 2 Elements  
(South Wall)





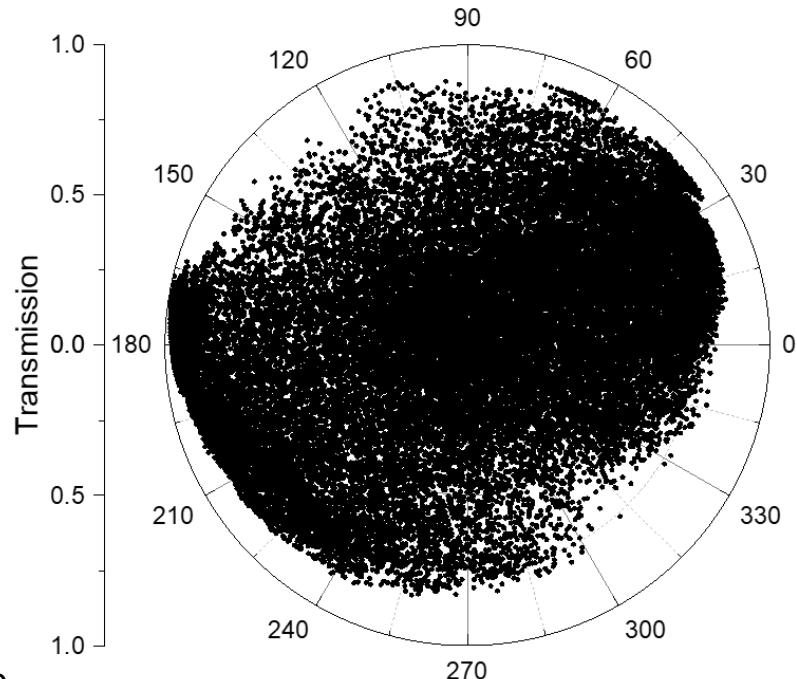
# Phase element design

## 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  $\mu\text{m}$

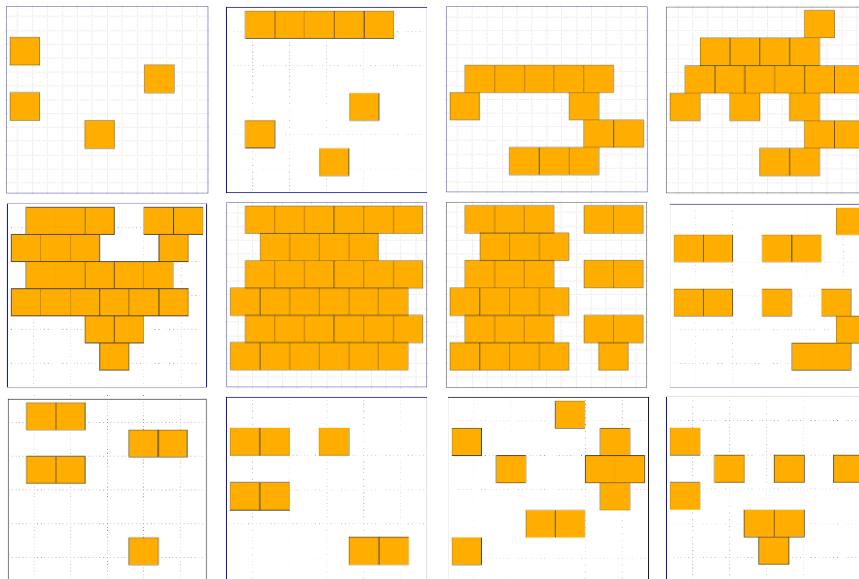


>80000 simulated structures

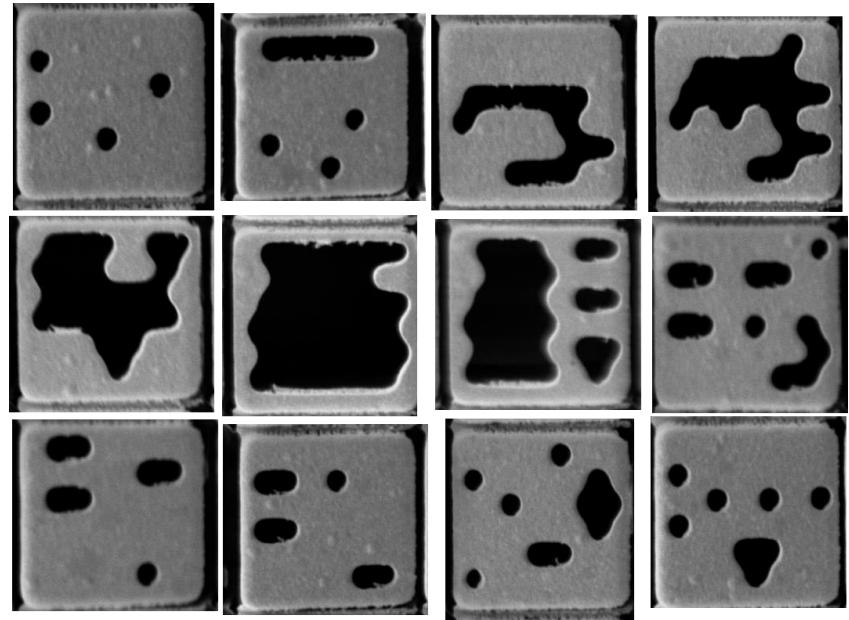


# Brick-Like element design

Design Phase Elements



Patterned Membranes

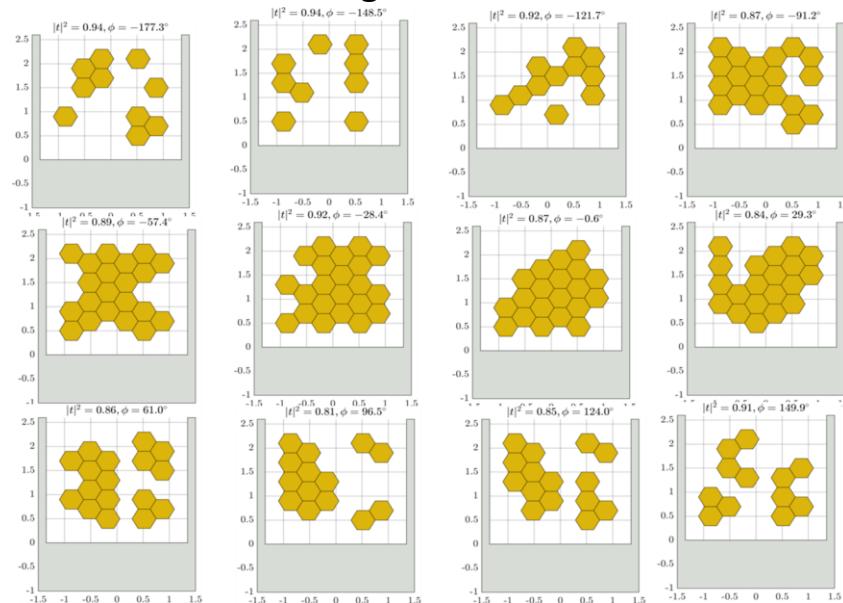


- Designed for transmission phase of  $0^\circ$  to  $330^\circ$  in  $30^\circ$  increments.
- Transmission for all elements is  $>65\%$ .

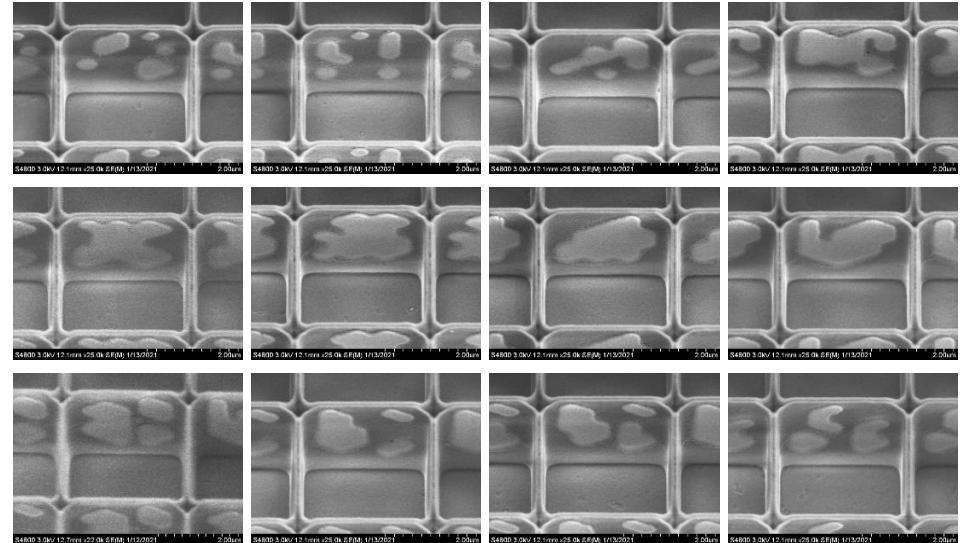


# Hexagonal Pixel design

## Design Phase Elements



## Patterned Membranes

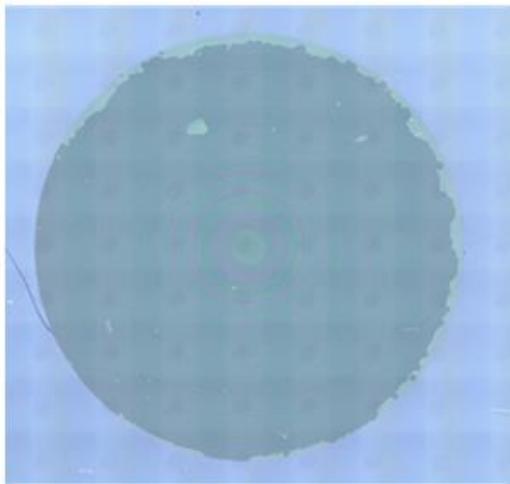


- Designed for transmission phase of 0° to 330° in 30° increments.
- Transmission for all elements is >80%.

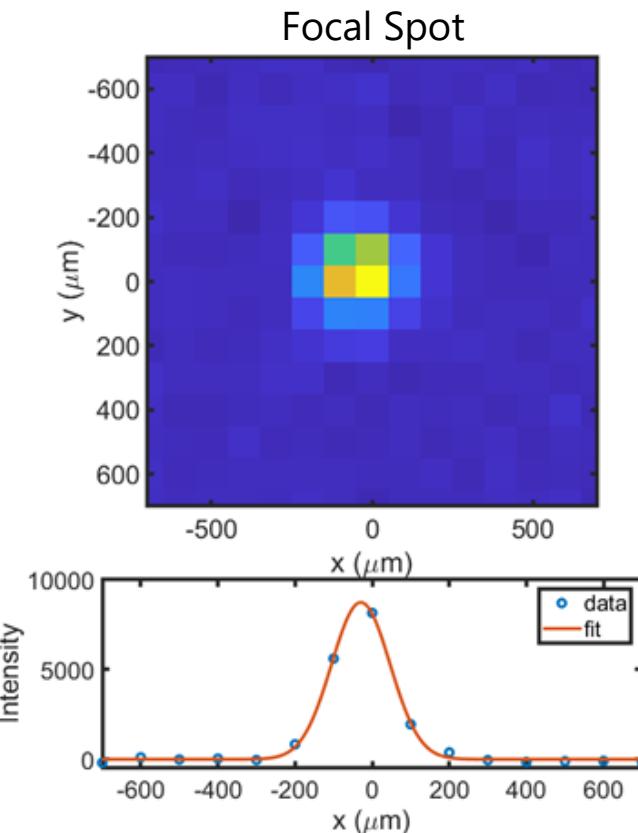


# Initial Lens Characterization

Lens Optical Image

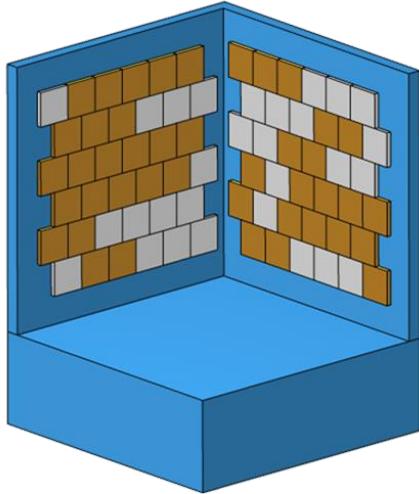


- Initial characterization shows focusing to  $\sim 350 \mu\text{m}$  spot.
- Further characterization underway to evaluate performance with optimized detection system.

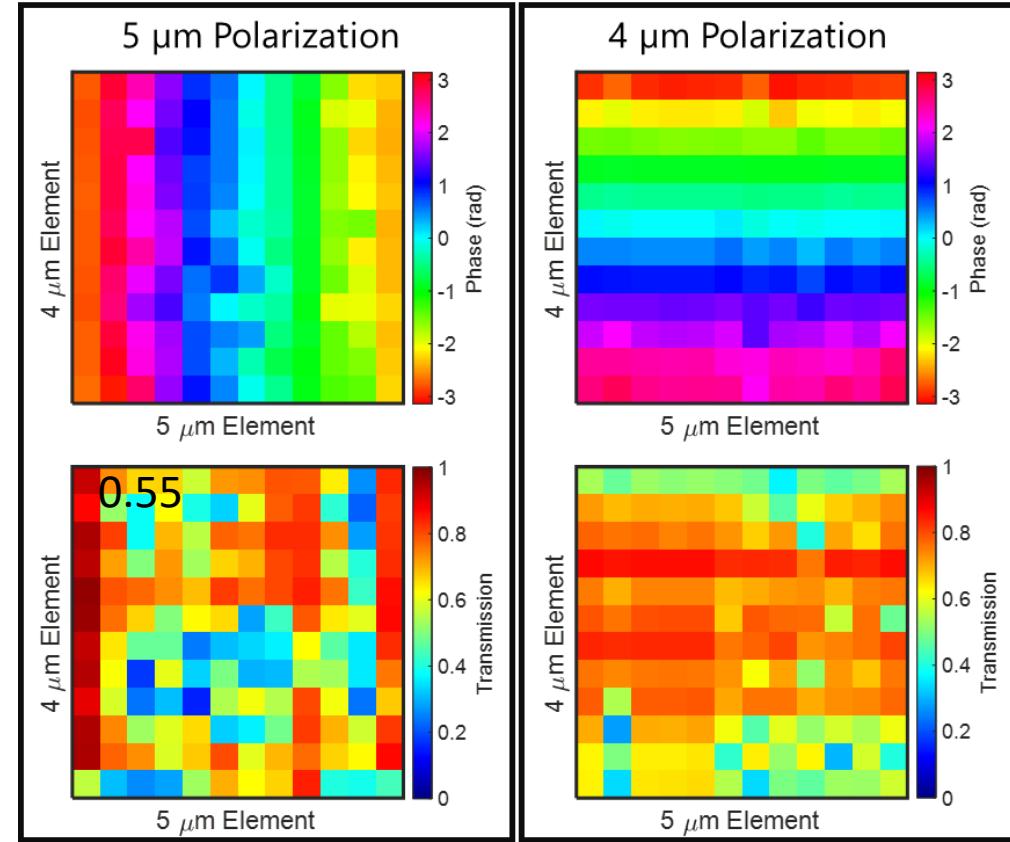




# Interwall Interaction



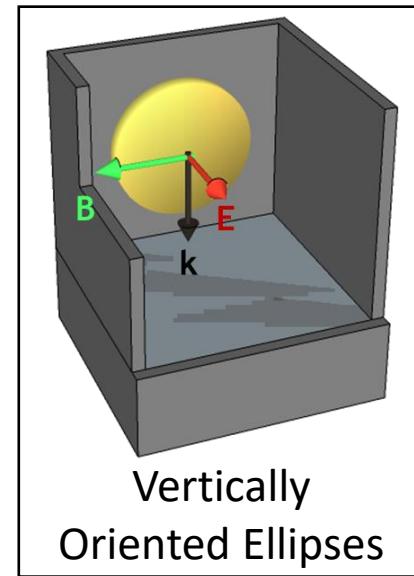
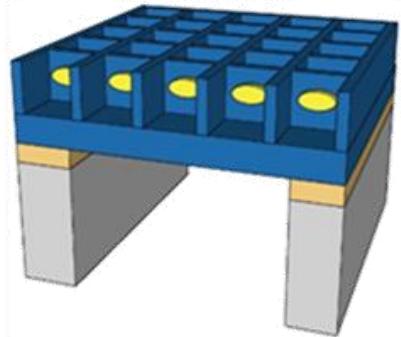
- Phase behavior nearly unchanged
- Transmission amplitude decreased for certain combinations





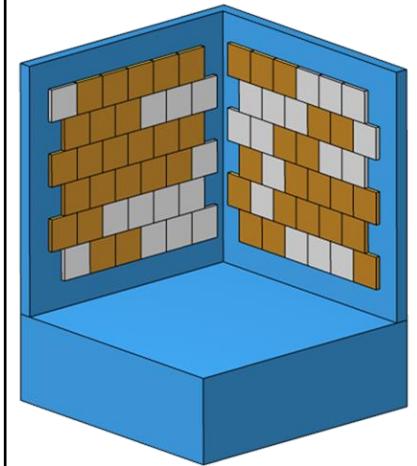
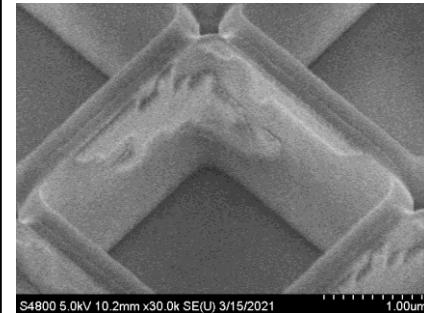
# Summary

## Membrane Projection Lithography



Vertically  
Oriented Ellipses

## Asymmetric Transmission



Multi-function  
Metasurfaces

