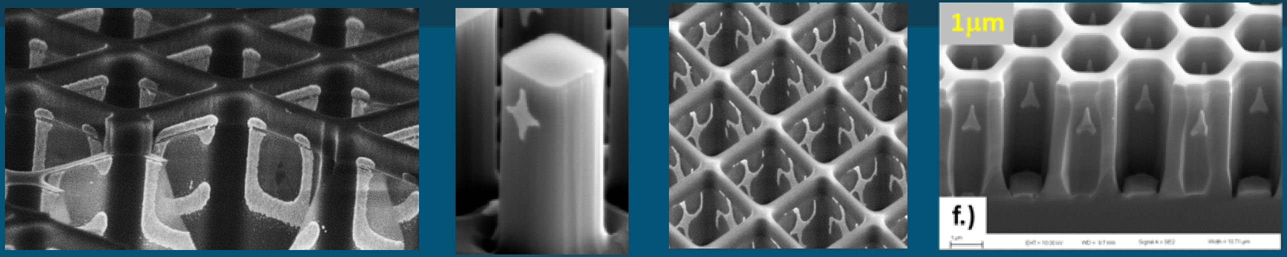
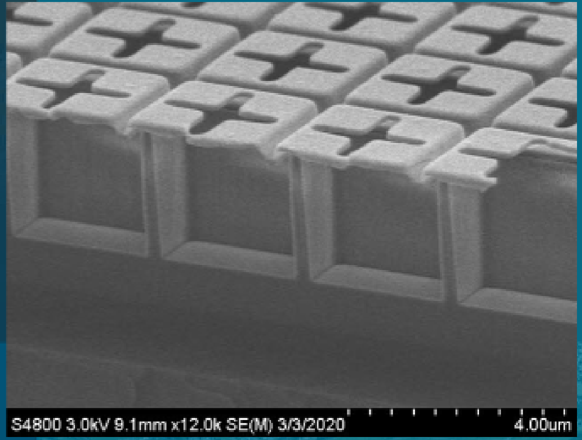
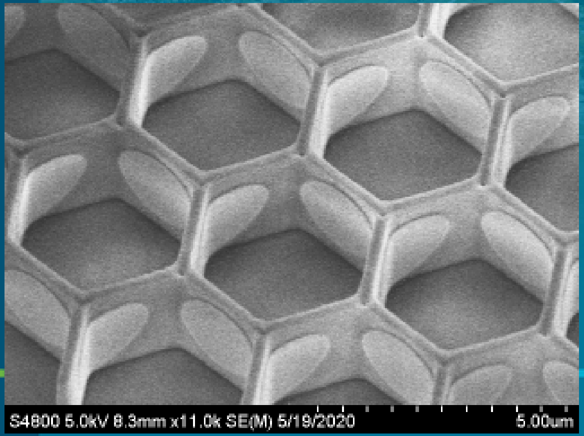
SAND2022-7216C

Coupling to Slab Modes in Suspended 3D Optical Metafilms







Katherine M. Musick and D. Bruce Burckel

dbburck@sandia.gov

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New Orleans, Louisiana

June 1, 2022

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Outline

1. 3D Metafilm Fabrication via membrane projection lithography (MPL)

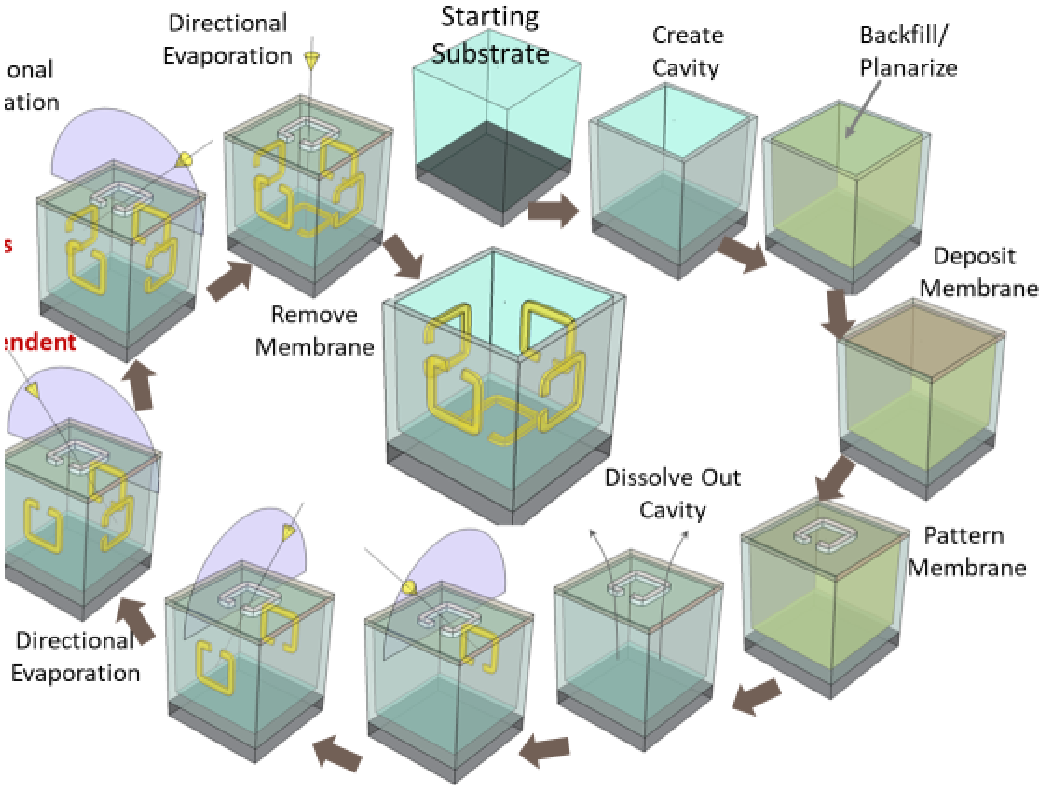
2. Periodically modulated dielectric matrix – photonic crystal slab modes

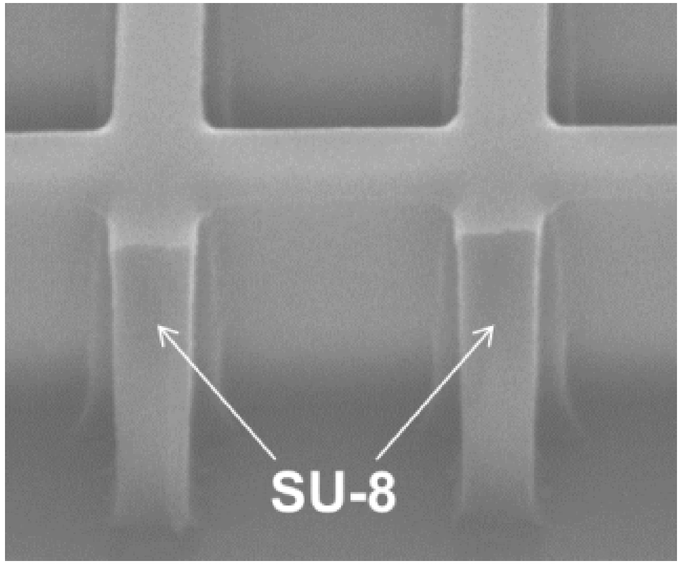
3. Coupling between plasmonic resonances and photonic crystal slab modes

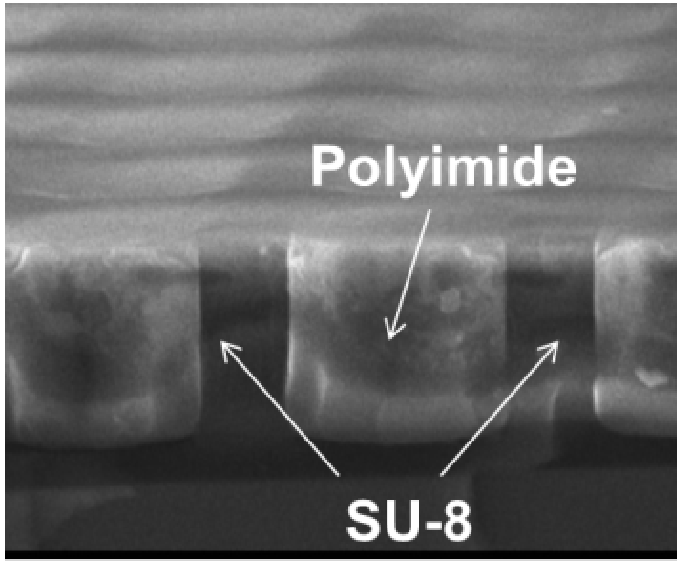
Membrane Projection Lithography

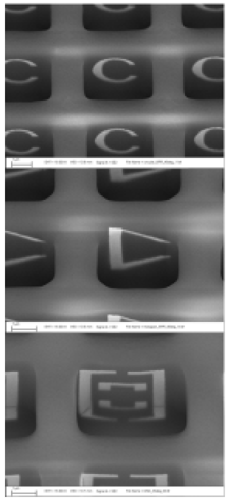
DB Burckel et. al., “Micrometer-scale cubic unit cell 3D metamaterials”
Adv. Mater. **22** 5053-5057 (2010).

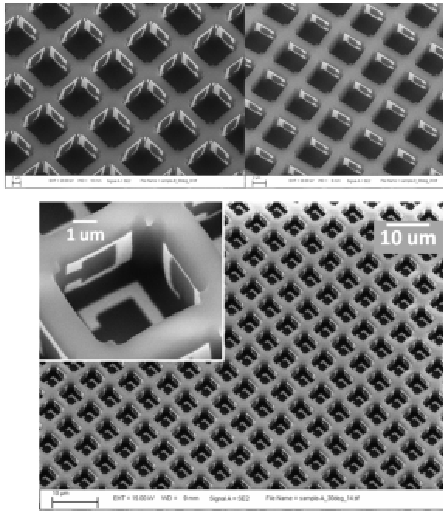
Polymer-Based Membrane Projection Lithography (2009)

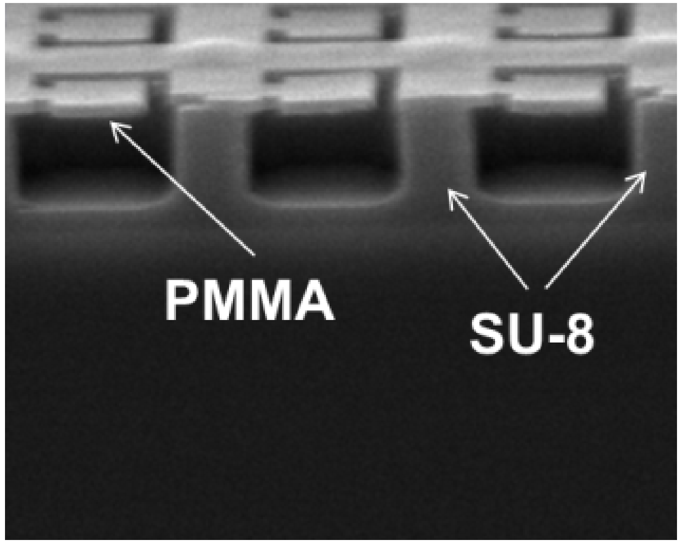








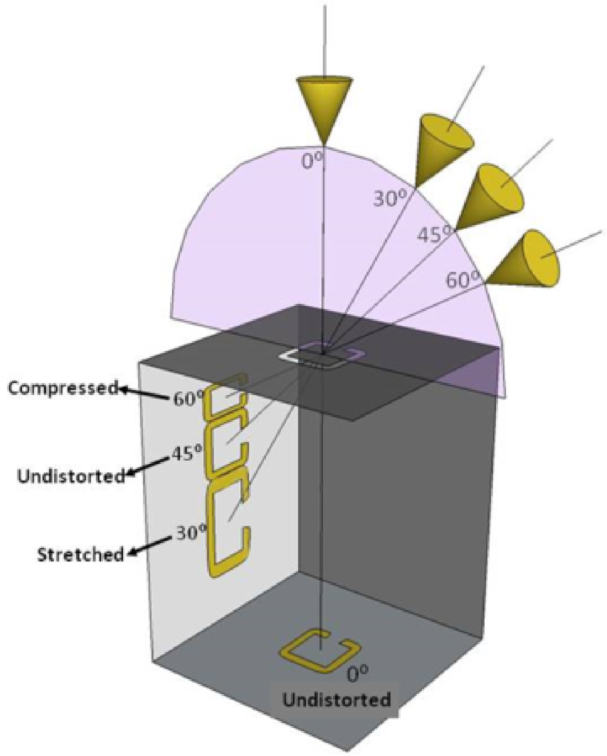




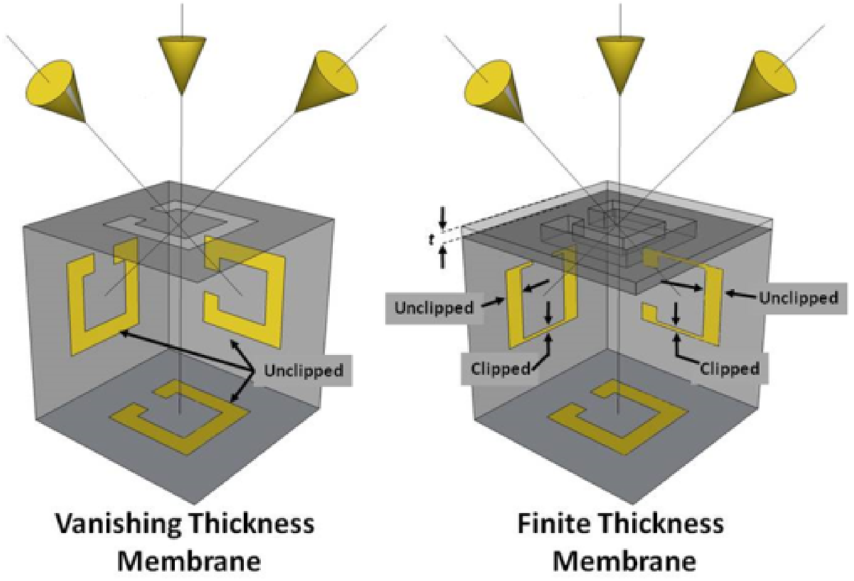
DB Burckel et. al., “Micrometer-scale cubic unit cell 3D metamaterials” Adv. Mater. **22** 5053-5057 (2010).

Sources of MPL Pattern Distortion

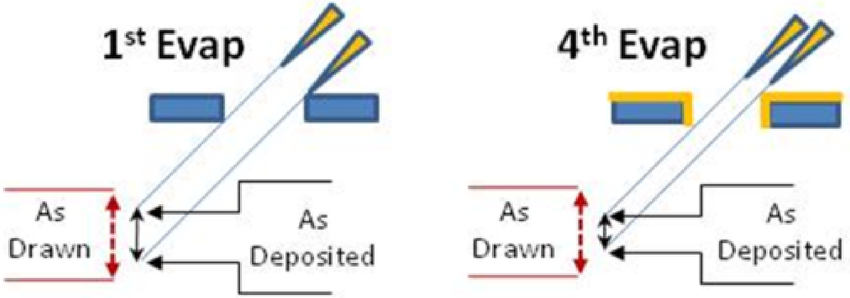
Projection at 45º Preserves Pattern Shape in Cubic Geometries



Real Membranes result in Linewidth Clipping

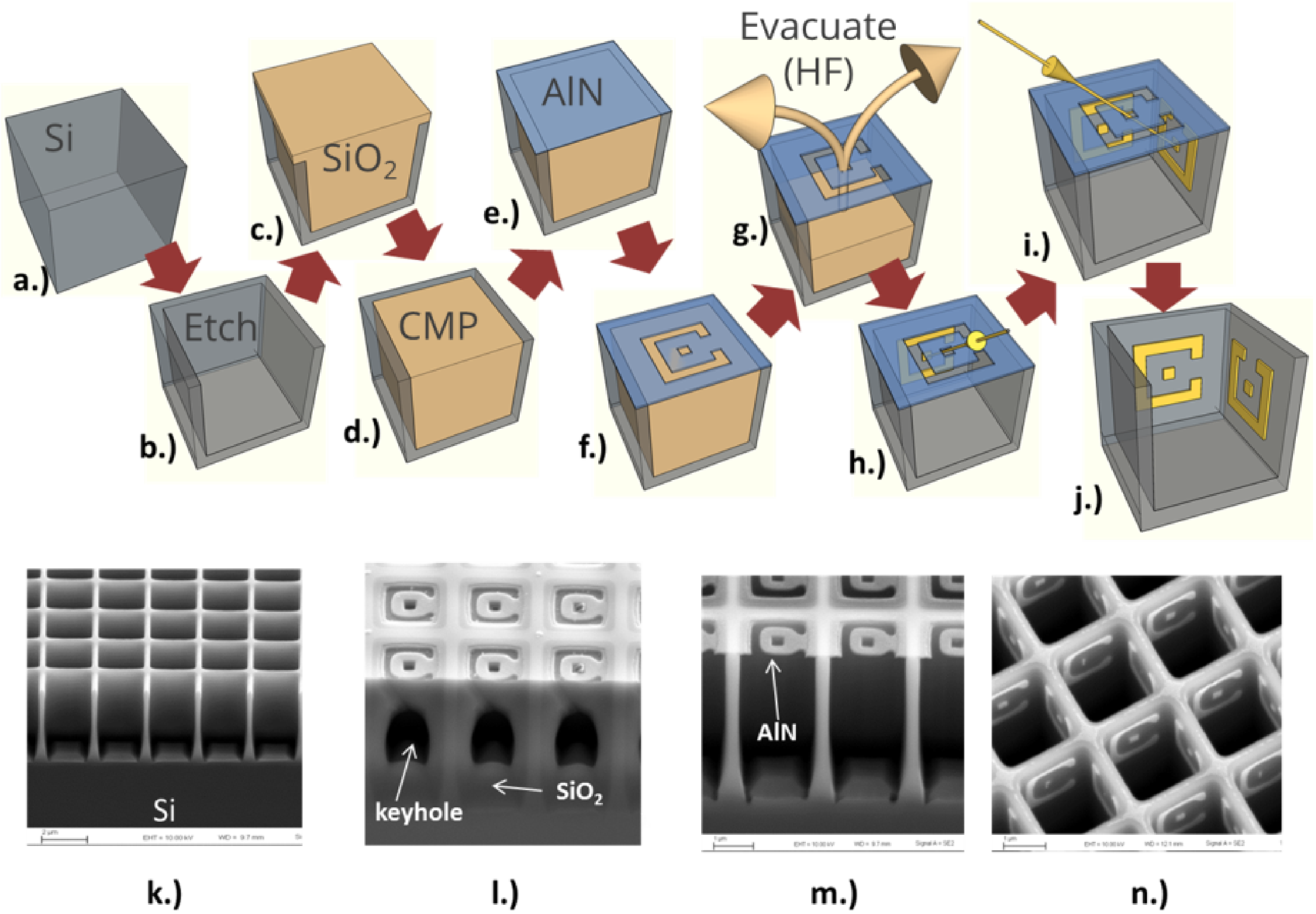


Multiple Evaporations result in Linewidth Thinning



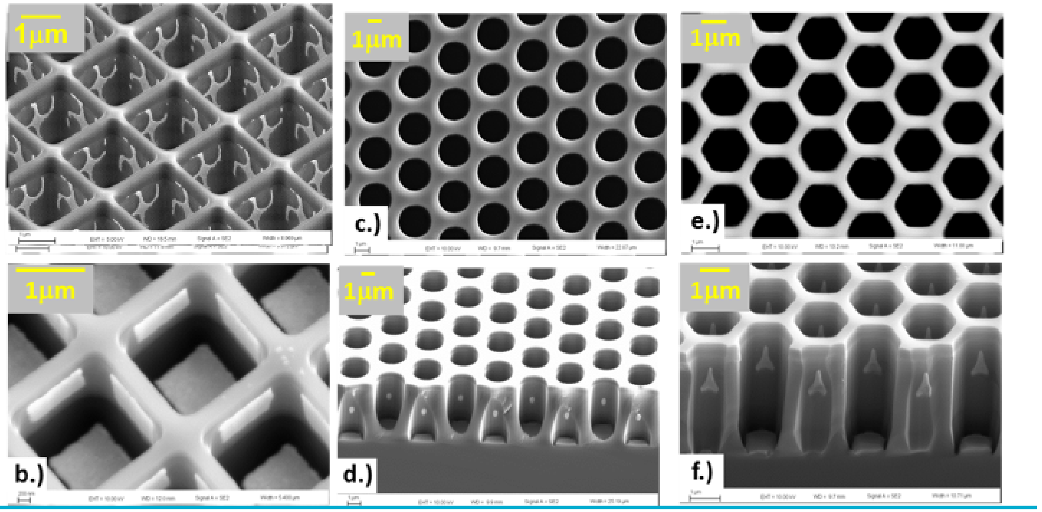
DB Burckel et. al., “Micrometer-scale cubic unit cell 3D metamaterials” Adv. Mater. **22** 5053-5057 (2010).

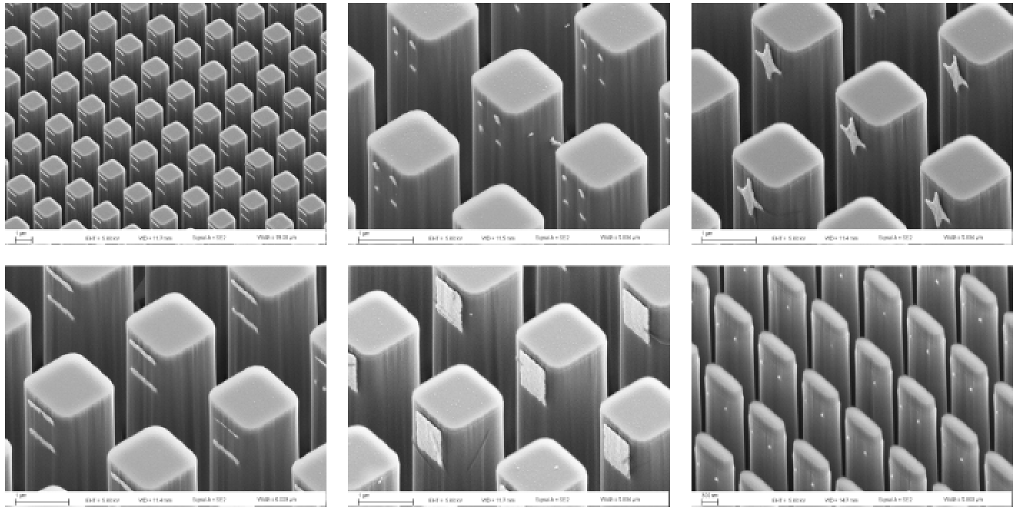
CMOS Compatible MPL (2015)



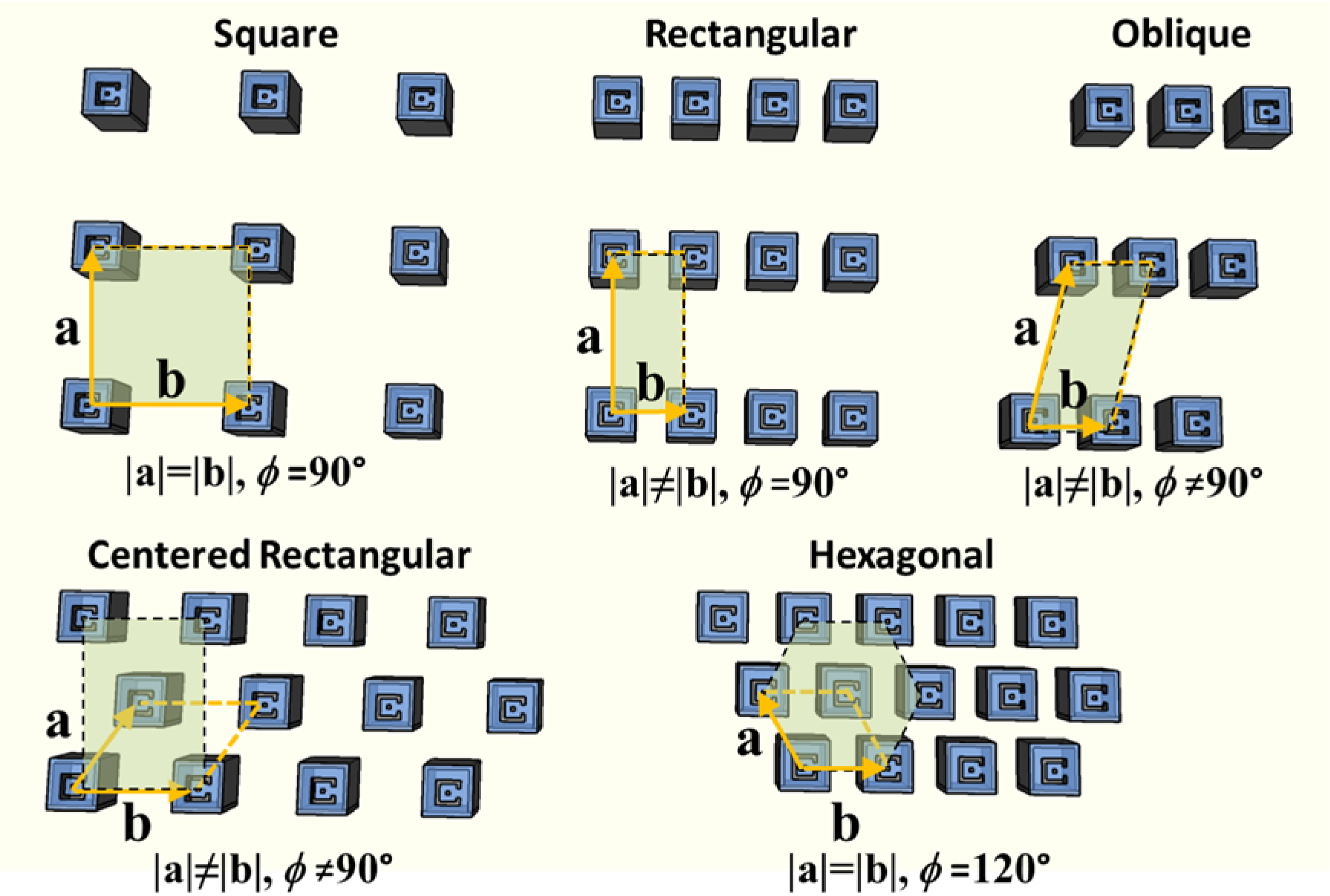
DB Burckel et. al., “Micrometer-scale fabrication of complex 3D lattice + basis structures in silicon” Opt Mat.. Exp. **10** , 2231-2239 (2015).

3D micron-scale Metamaterials



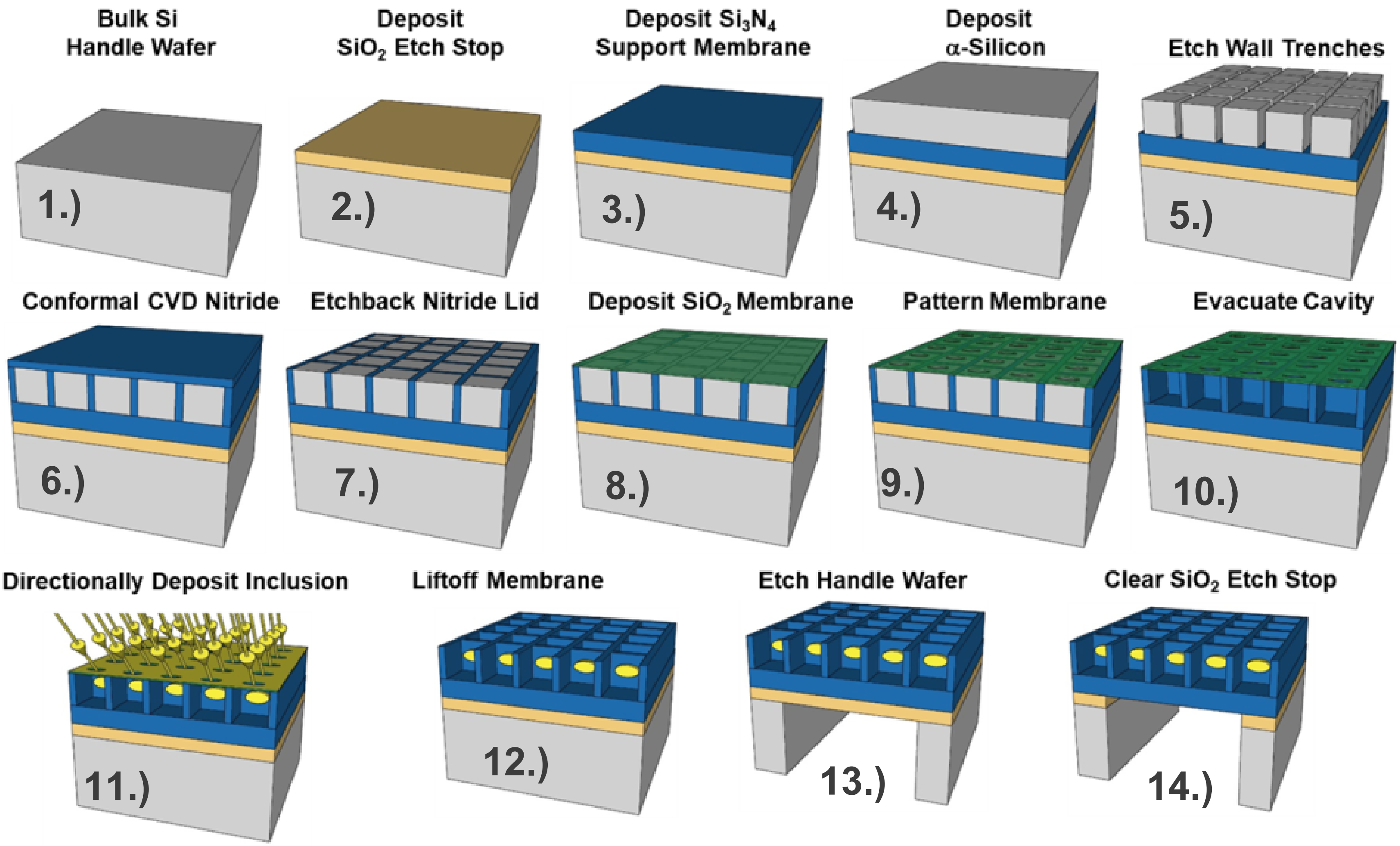


Any In-plane Lattice



DB Burckel et. al., “Micrometer-scale fabrication of complex 3D lattice + basis structures in silicon” Opt Mat.. Exp. **10** , 2231-2239 (2015).

Wall-First Membrane Projection Lithography Process Flow (2020)



1.) Bulk Si Handle Wafer

2.) Deposit SiO_2 Etch Stop

3.) Deposit Si_3N_4 Support Membrane

4.) Deposit α-Silicon

5.) Etch Wall Trenches

6.) Conformal CVD Nitride

7.) Etchback Nitride Lid

8.) Deposit SiO_2 Membrane

9.) Pattern Membrane

10.) Evacuate Cavity

11.) Directionally Deposit Inclusion

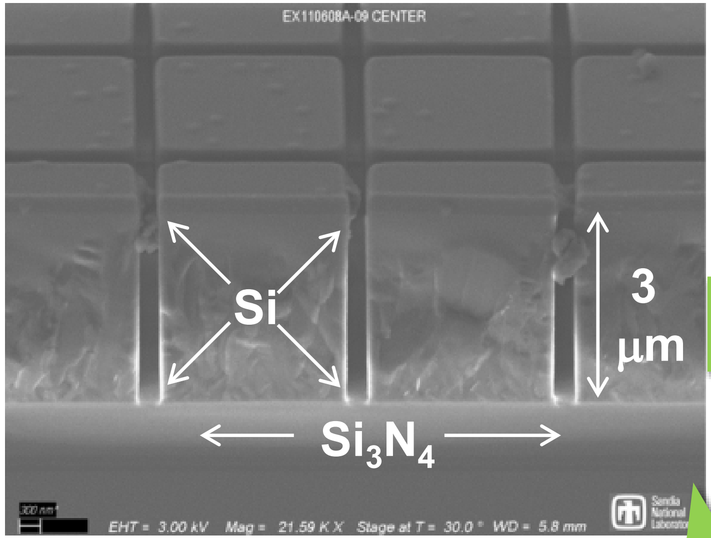
12.) Liftoff Membrane

13.) Etch Handle Wafer

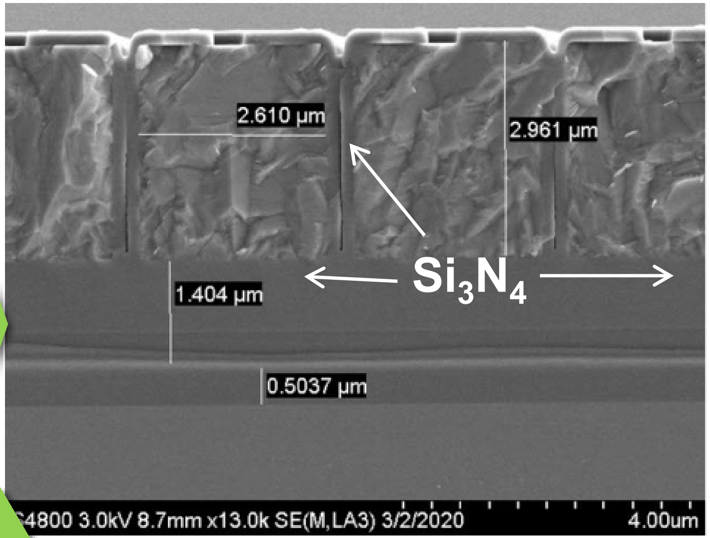
14.) Clear SiO_2 Etch Stop

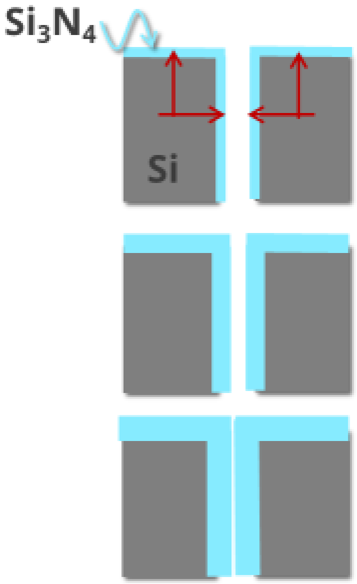
Process Flow Snapshot SEMs

Trench Etch

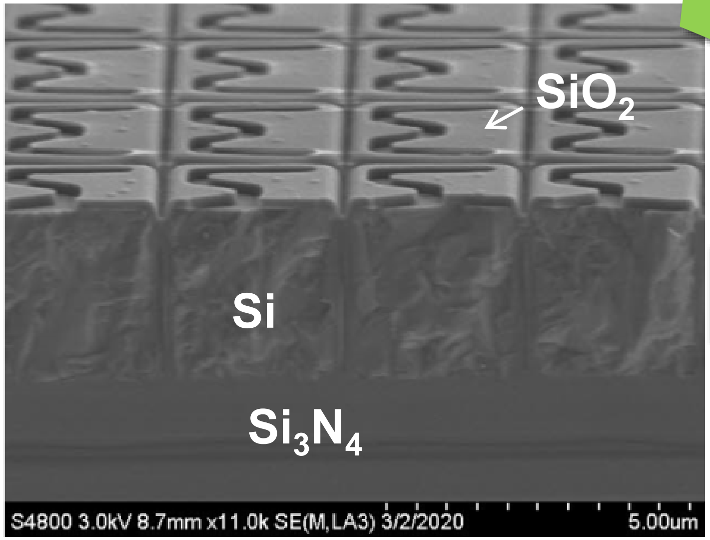


Trench Backfill

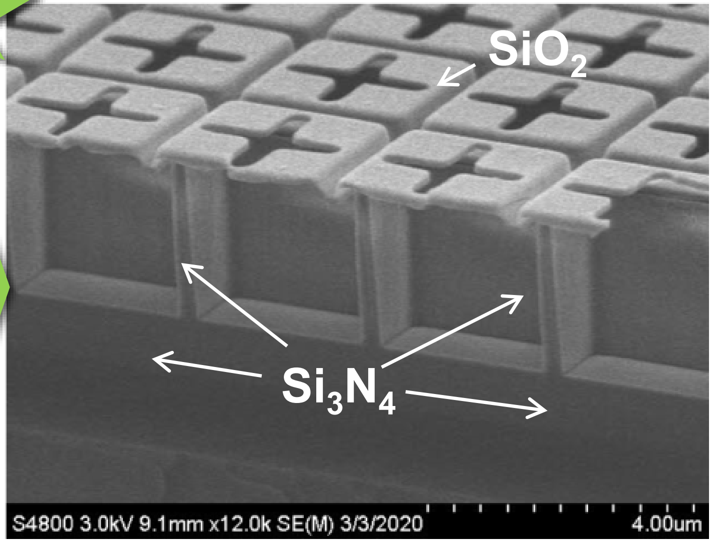




Membrane Patterning

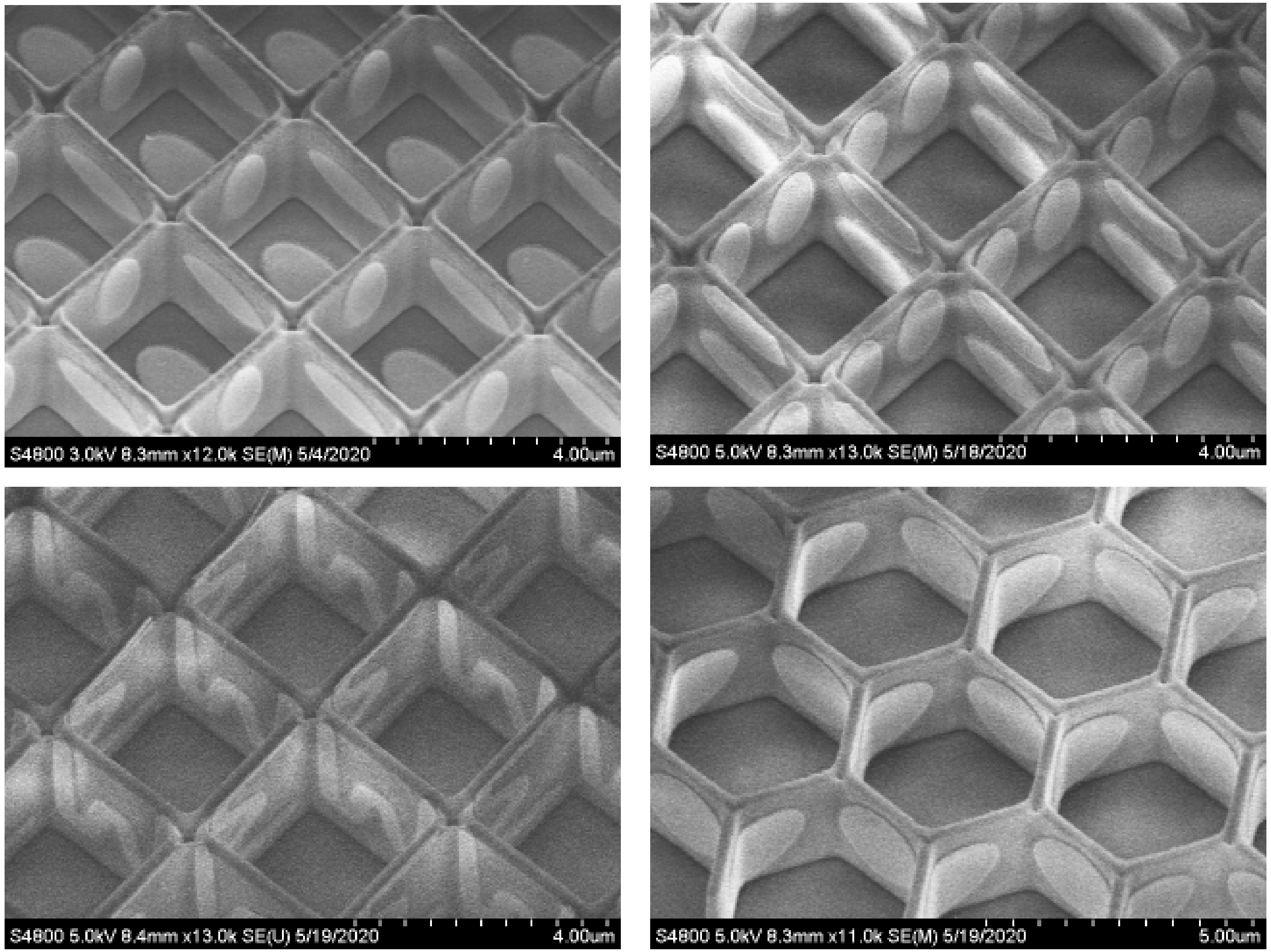


Cavity Evacuation (XeF_2)

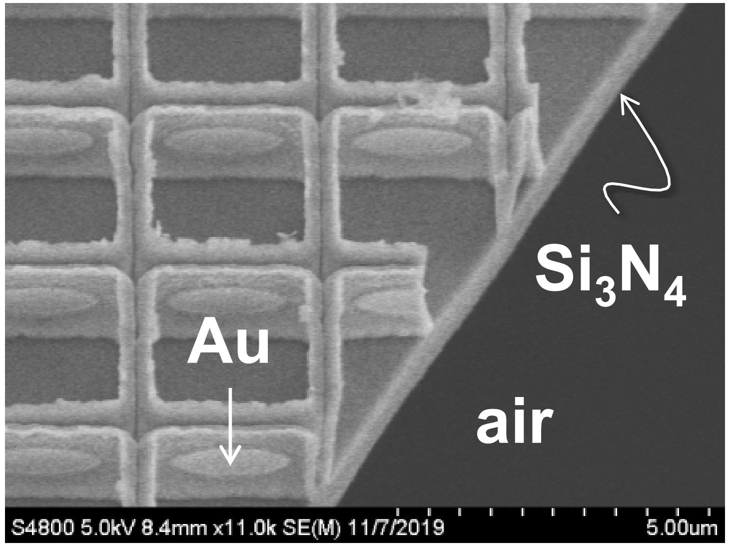


DB Burckel et. al., “Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films” Opt. Exp. **28** (8), 10836-10846 (2020).

Decorated Unit Cells – 3D Metafilms

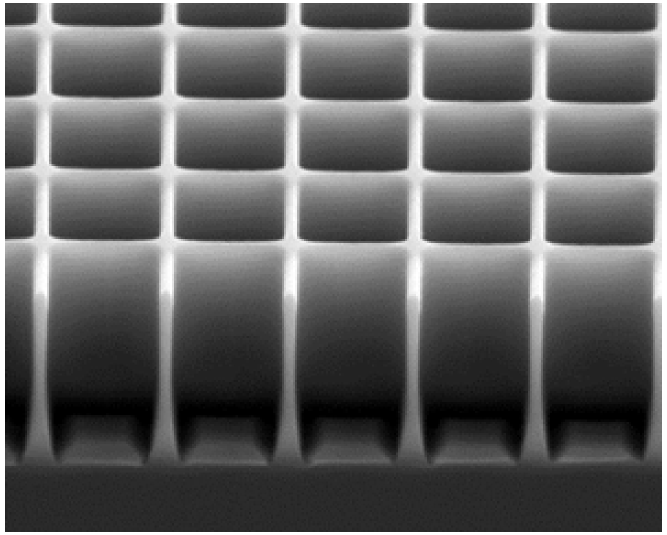


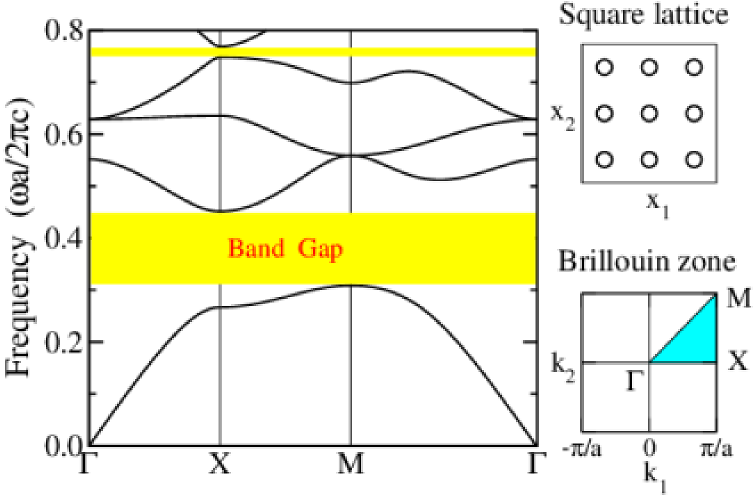
Handle Wafer Removed



DB Burckel et. al., “Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films” Opt. Exp. **28** (8), 10836-10846 (2020).

Photonic Crystal Slab Modes

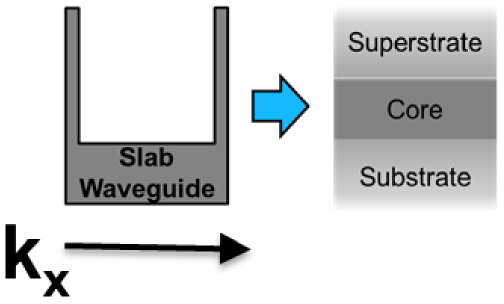




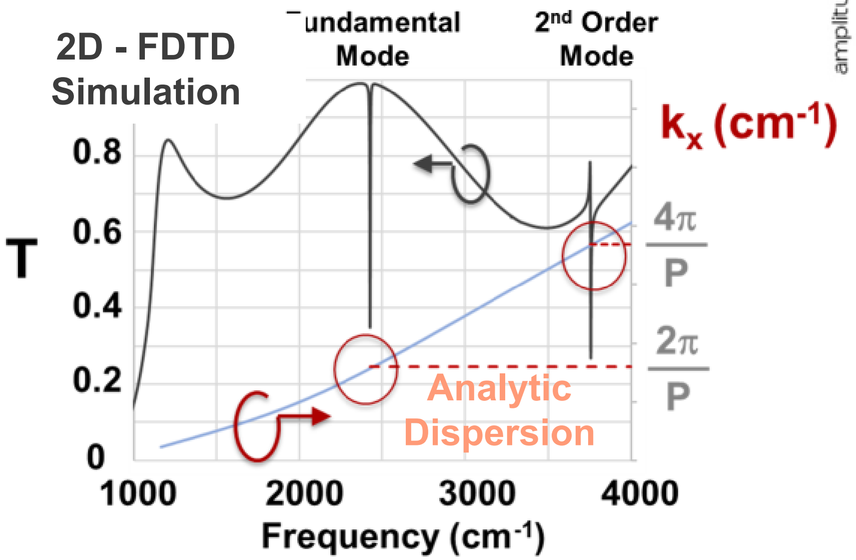
DB Burckel et. al., “Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films”
Opt. Exp. **28** (8), 10836-10846 (2020).

Analyzing the Scattering Spectrum : Empty Boxes

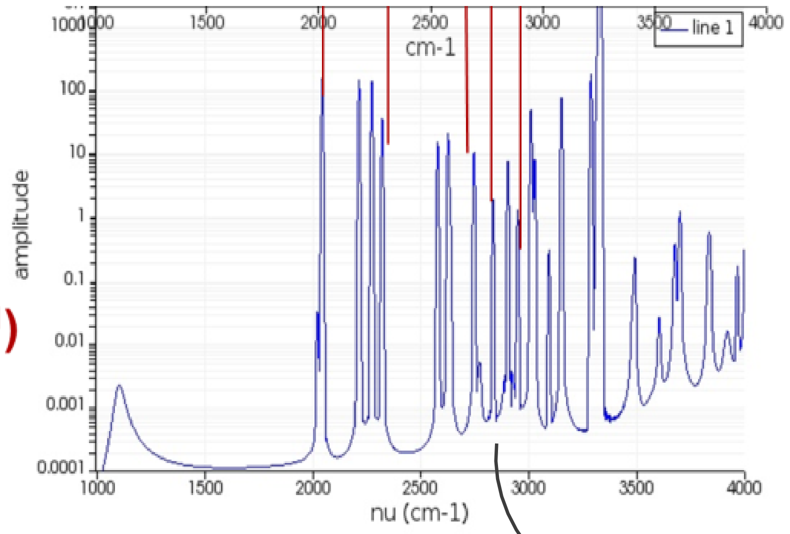
Periodic Unit Cell Array



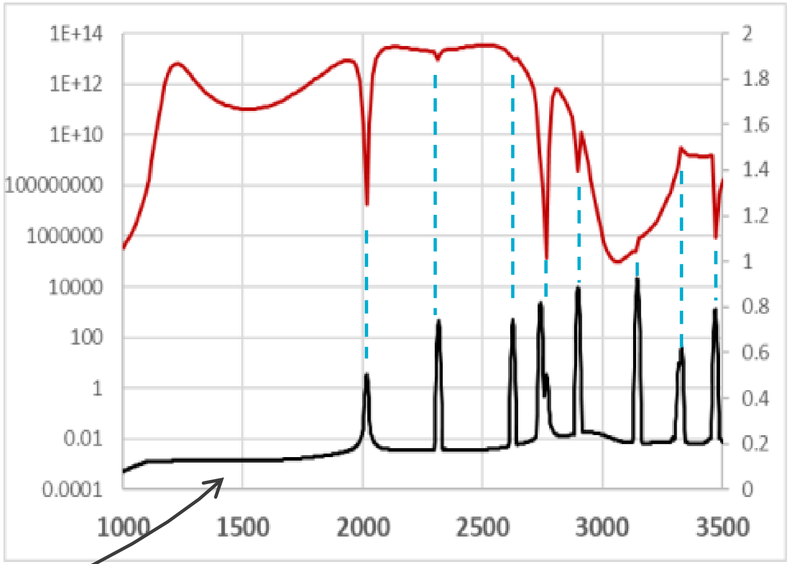
2D - FDTD Simulation



PSD – all allowed modes in matrix



3D - FDTD Simulation

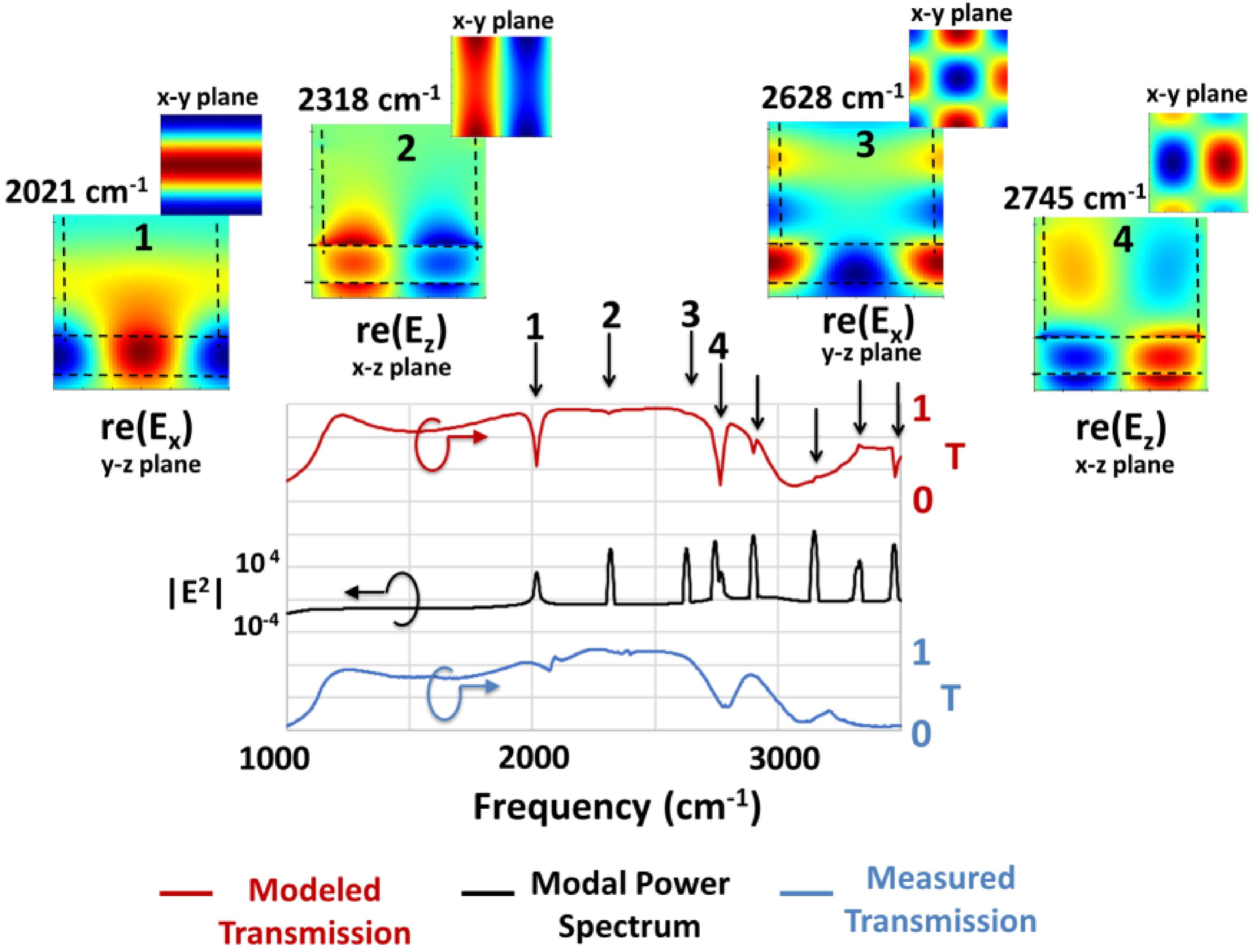


Subset of all allowed modes

PSD – modes coupled to external plane wave excitation

DB Burckel et. al., "Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films" Opt. Exp. **28** (8), 10836-10846 (2020).

Analyzing the Scattering Spectrum: Empty Boxes



DB Burckel et. al., "Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films" Opt. Exp. **28** (8), 10836-10846 (2020).

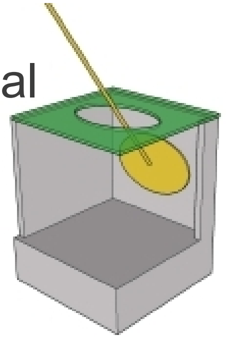
Coupling between Photonic Crystal Slab Modes and 3D Plasmonic Meta-atoms

DB Burckel et. al., “Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films” Opt. Exp. **28** (8), 10836-10846 (2020).

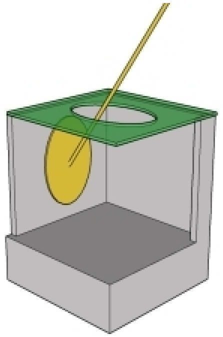
Decorating with plasmonic meta-atoms

Same Membrane Pattern Different Evaporation Direction

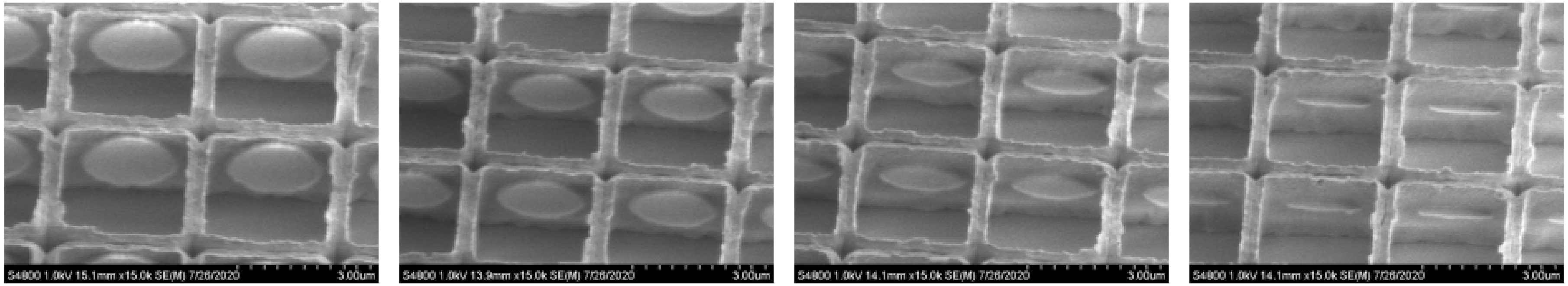
Horizontal Ellipses



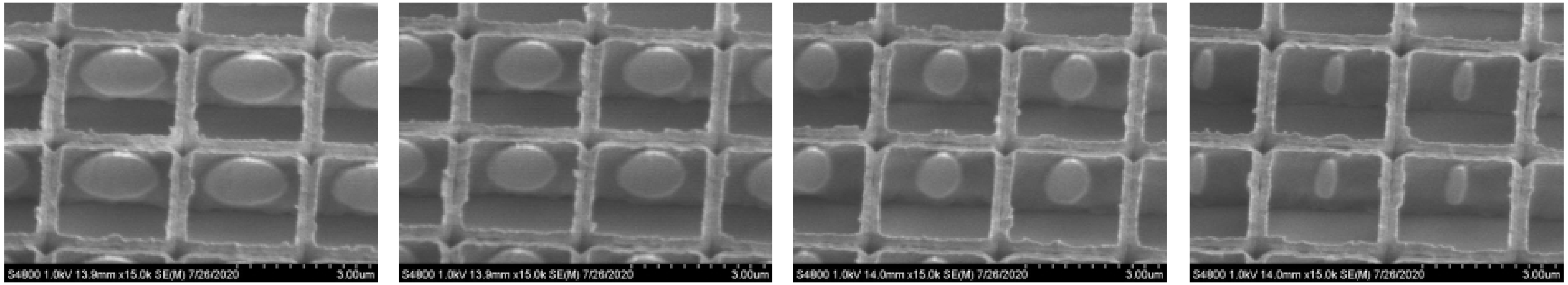
Vertical Ellipses



North wall evaporations

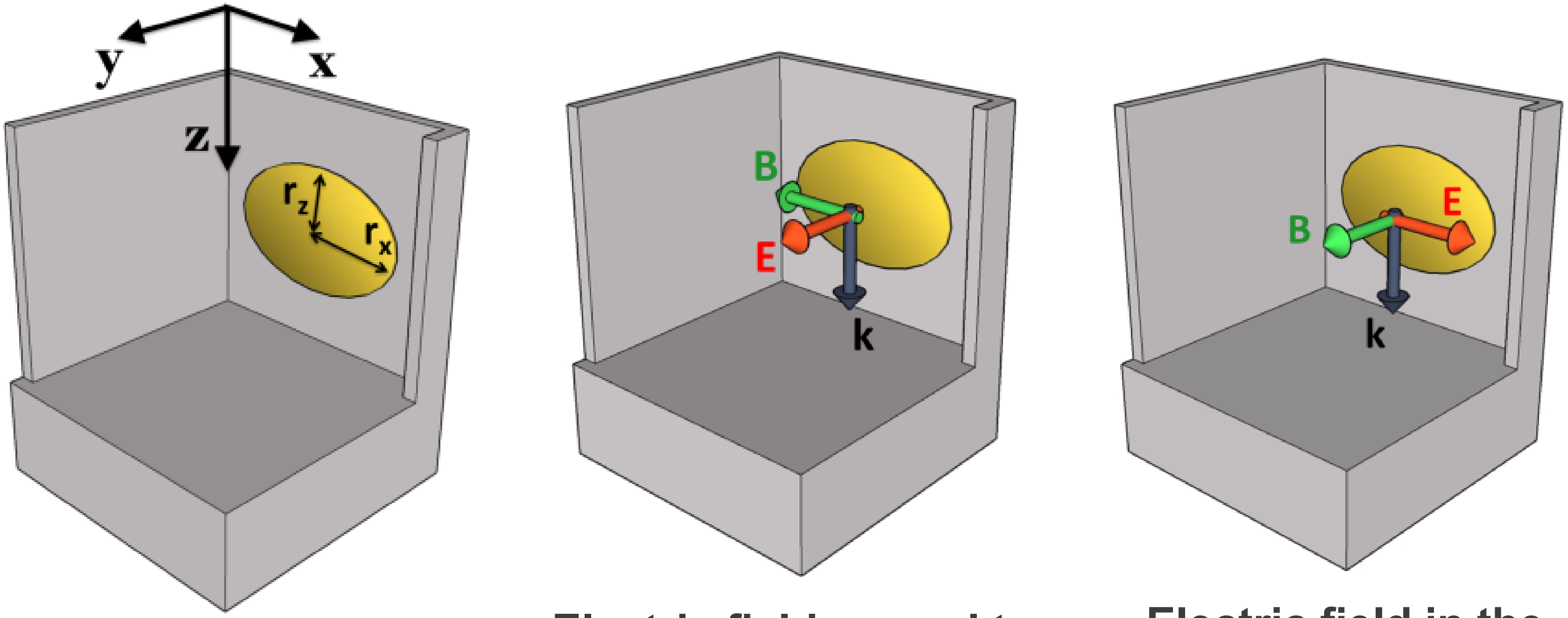


East wall evaporations



DB Burckel et. al., “Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films”
Opt. Exp. **28** (8), 10836-10846 (2020).

Polarization in 3D Metafilms



Transparent Polarization

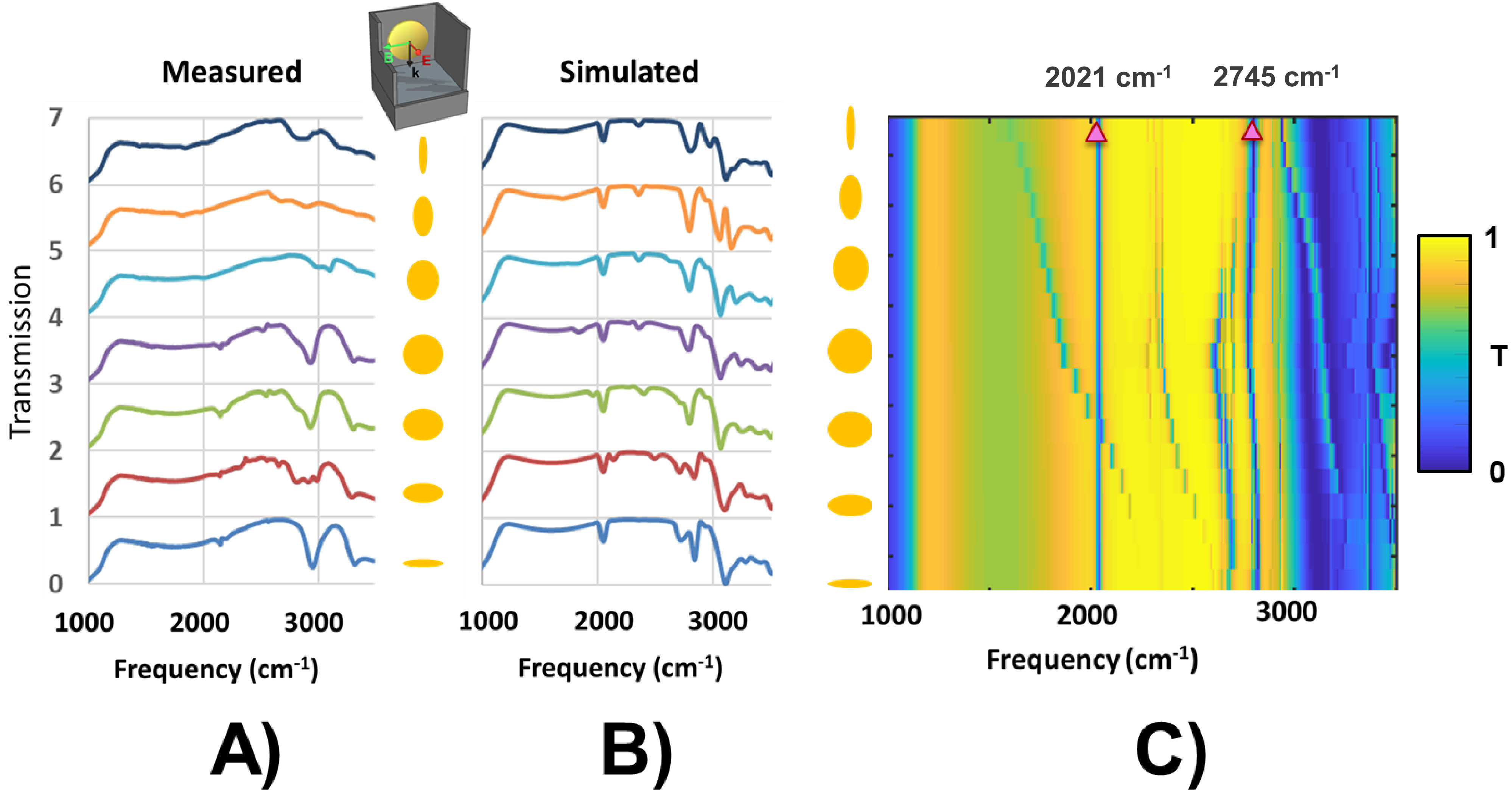
Resonant Polarization

Electric field normal to plane of ellipse

Electric field in the plane of ellipse

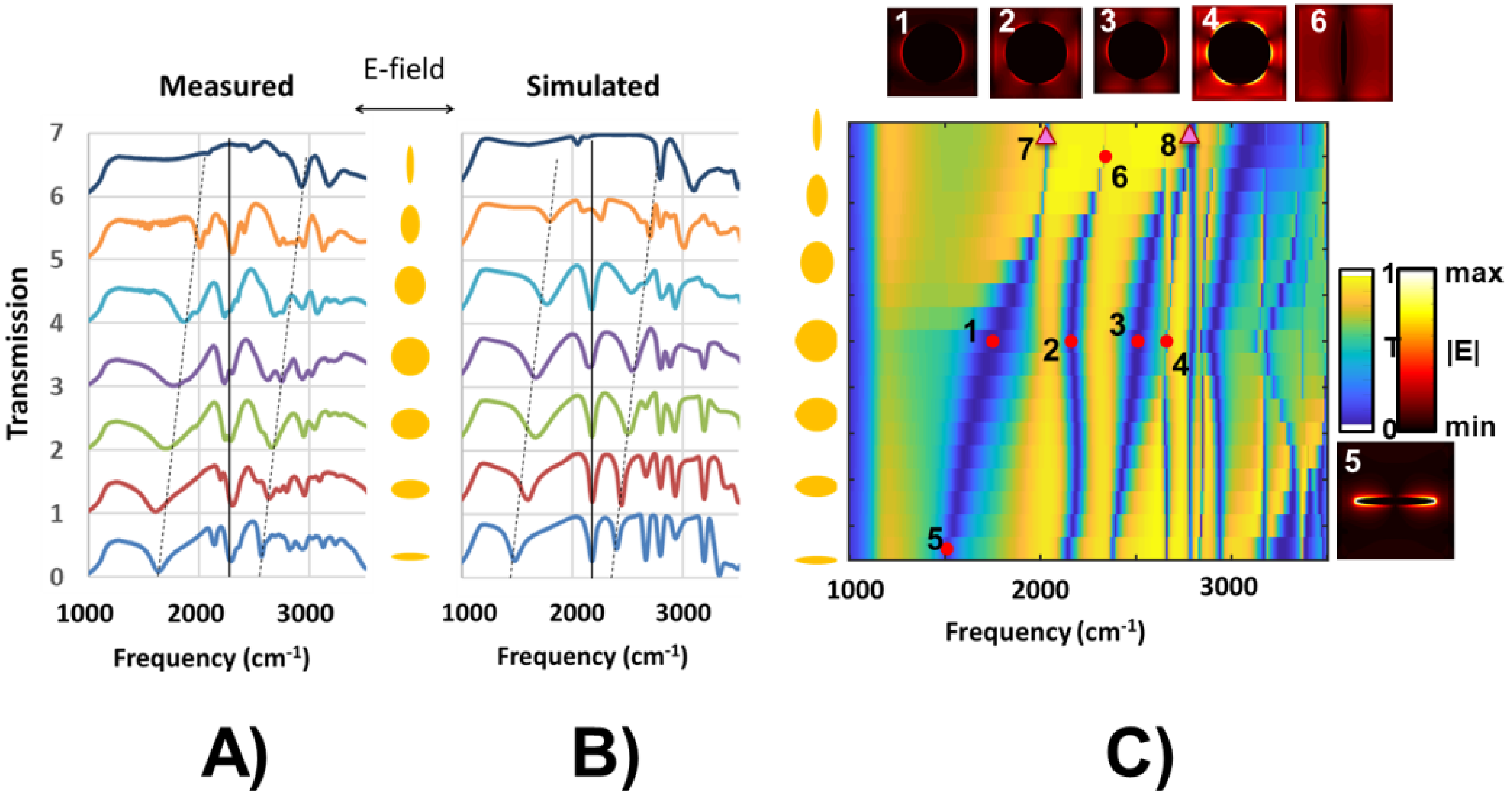
DB Burckel, M Goldflam, KM Musick, PJ Resnick, G Armelles, and MB Sinclair, “Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films” Optics Express **28** (8), 10836-10846 (2020).

Transparent Polarization



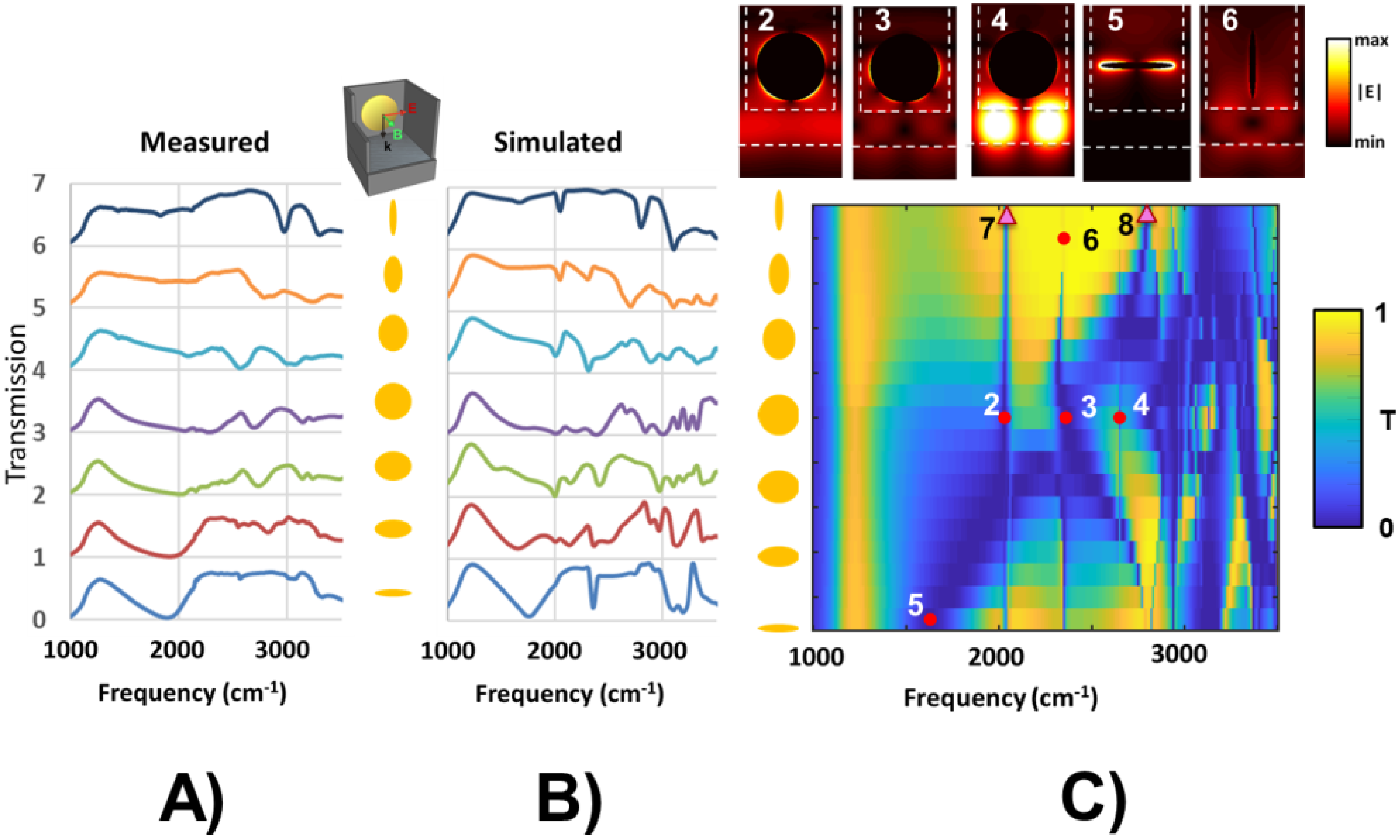
DB Burckel et. al., “Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films”
Opt. Exp. **28** (8), 10836-10846 (2020).

Ellipses on the Floor



DB Burckel et. al., "Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films" Opt. Exp. **28** (8), 10836-10846 (2020).

Resonant Polarization



DB Burckel et. al., “Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films” Opt. Exp. **28** (8), 10836-10846 (2020).

Conclusions

1. Wall-first membrane projection lithography fabrication approach is a robust method for creation of infrared 3D metafilms

2. 3D metafilms combine and couple photonic crystal slab modes and plasmonic particle modes

3. Planar ellipses on the floor respond to both incident polarizations

4. Vertical ellipses exhibit a resonant response to linear polarization with e-field in the plane of the ellipse, while being largely transparent to the orthogonal polarization

5. Retardation effects broaden the spectral width of resonances for vertically oriented ellipses.

Funding and Collaboration

- Funding : DARPA Extreme, NGA, SNL-LDRD
- SNL Collaborators: Michael Goldflam (Systems and Technology Research, San Diego, CA), Kate Musick, Michael Sinclair, Paul Resnick, Rob Jarecki
- External Collaborators: Gaspar Armelles -Microelectronic Institute of Madrid (IMM-CNM, CSIC) ;