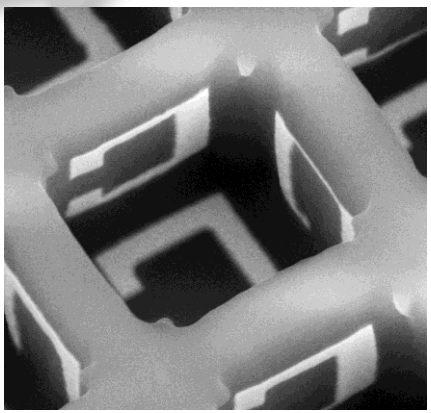
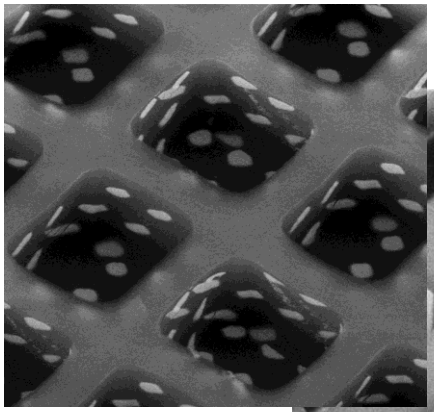
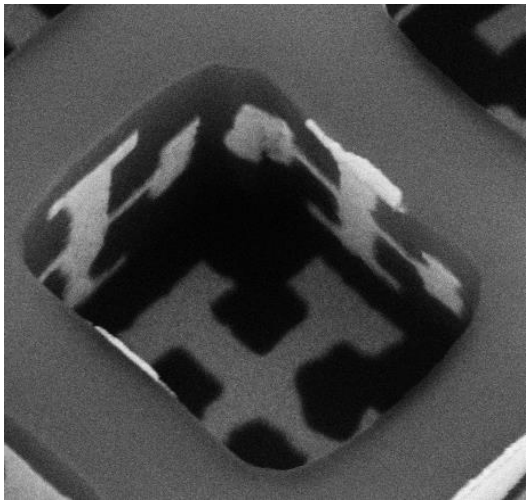
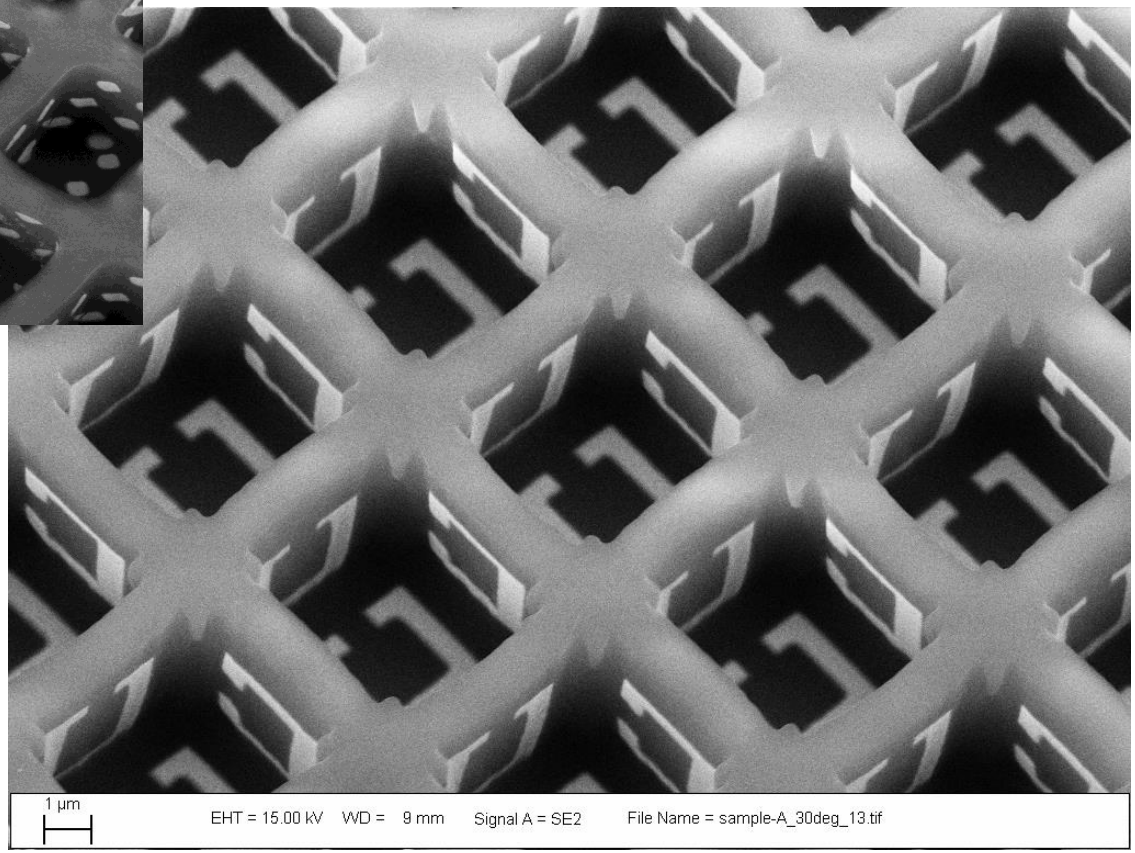
Membrane Projection Lithography

SAND2013-7376P









D. Bruce Burckel, Sandia National Laboratories

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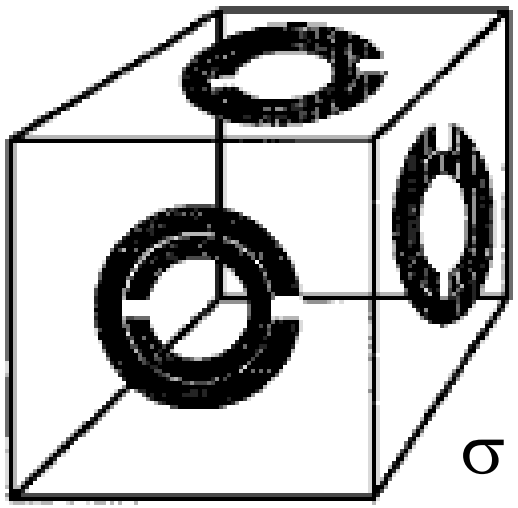
Translating a Pendry Cube from Microwave To Optical Frequencies

RF/Microwave

Line Width ~mms



$a \sim cms$

$\sigma \sim \infty$

Infrared

$\mu_r \sim 1$

$1 < \varepsilon_r < 30$

Cavity Fill Material

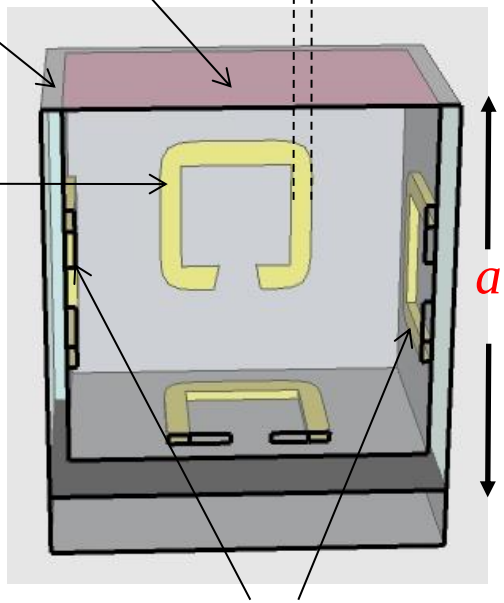
Line Width

~100s nm

Matrix Material

Inclusion Material

$\sigma \neq \infty$



a ~μms

Resonators Oriented Out-Of-Plane

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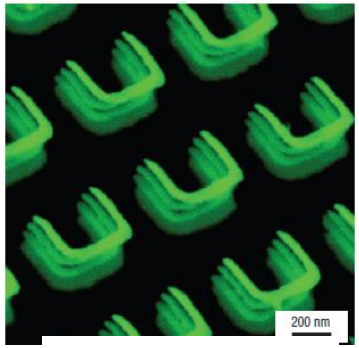
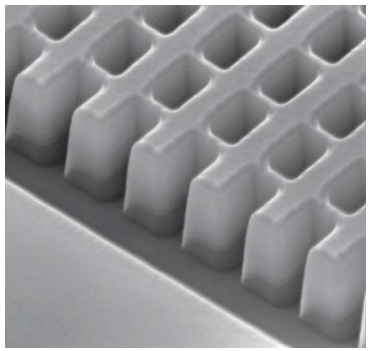
Examples of micro/nanoscale 3D Fabrication Approaches

Layer-by-layer

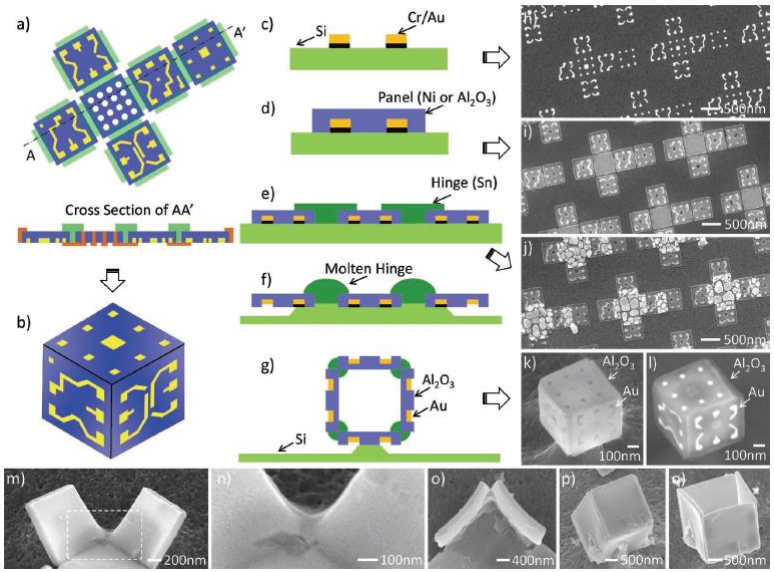


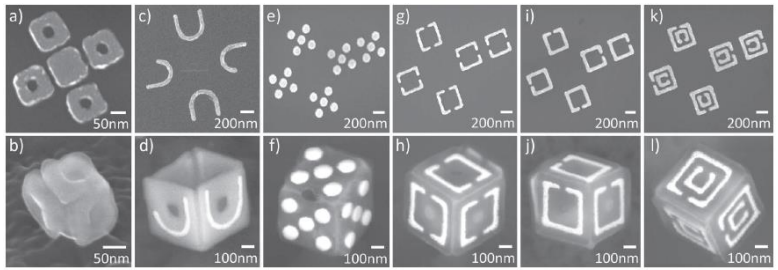
N. Liu, et. al.
Nat. Mat., 7,
pp 31-37, (2008)



J. Valentine, et. al.
Nature, 455,
pp 376-U32, (2008)

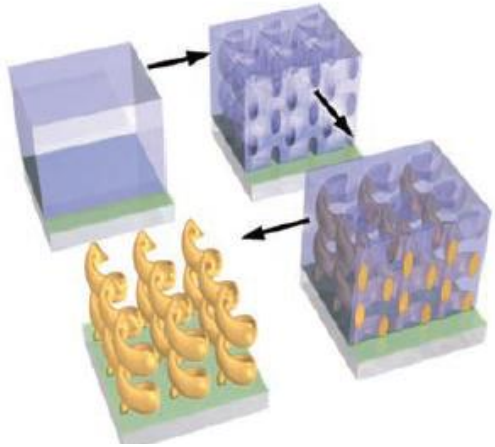
Nano Origami

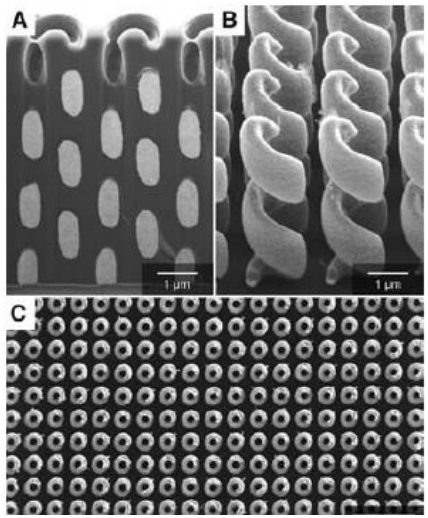




J.H. Cho, et. al. Small, 7,
pp 1943-1948, (2011)

Direct Laser Write

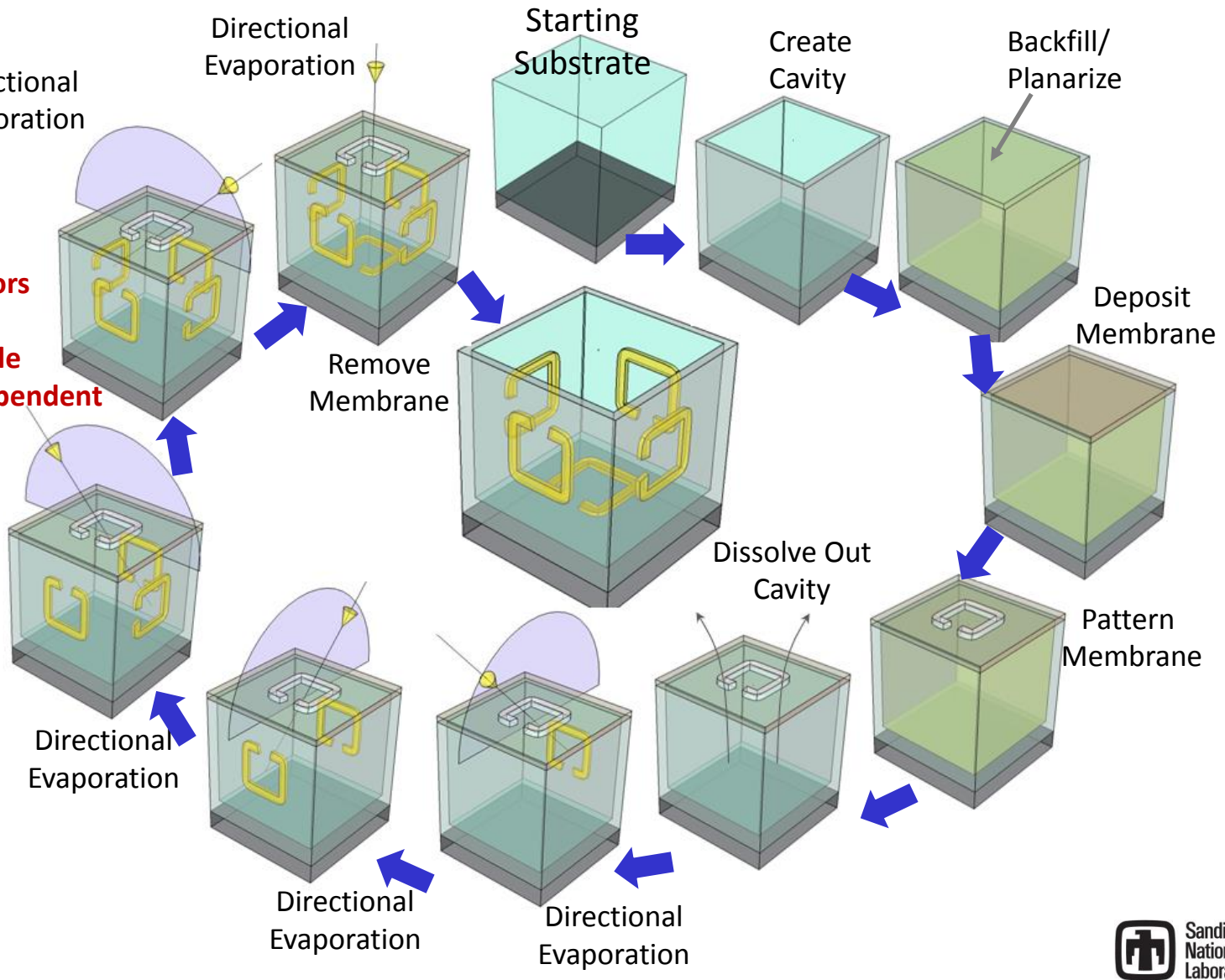




J.K. Gansel, et. al. Science, 325,
pp 1513-1515, (2009)

Membrane Projection Lithography: MPL

- **Out-of-plane resonators**
- **Planar lithography**
- **Many patterns possible**
- **Cavity geometry independent of resonator pattern**
- **Scalable**
- **Layer-by-layer → 3-D**



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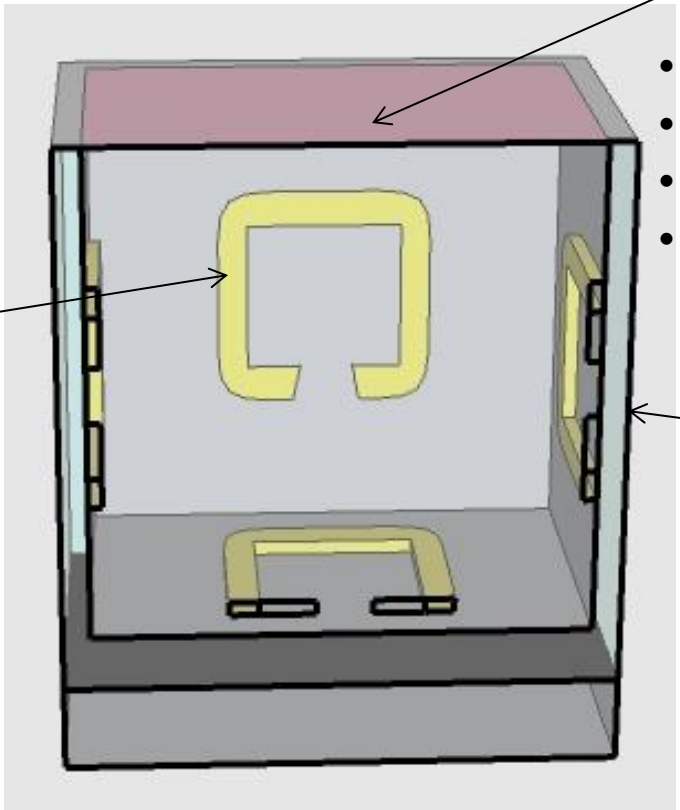
Material Components Available in MPL Fabrication

Cavity Backfill Material

- SU-8
- Polyimide
- Spin-on Dielectrics
- CVD dielectrics (with CMP)



Inclusion Material

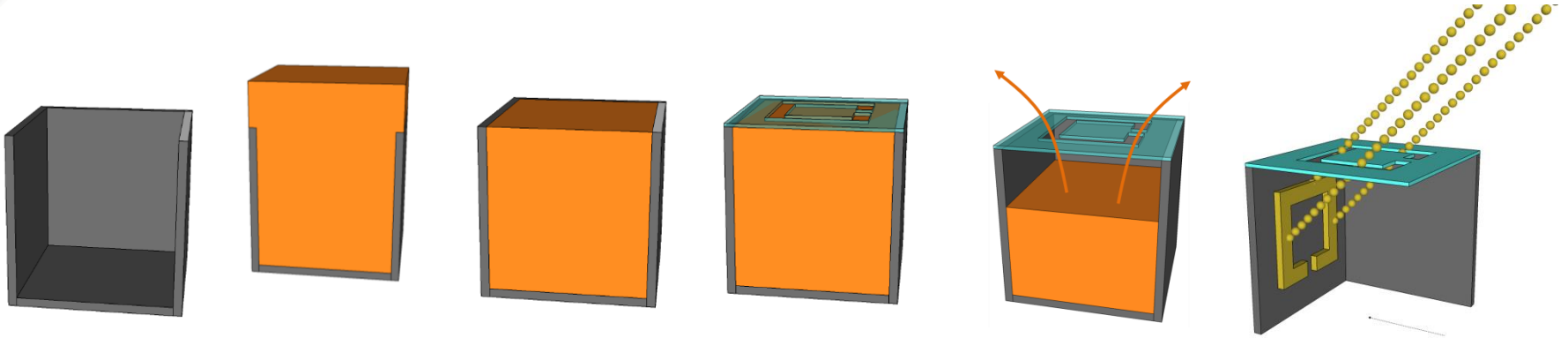
- Metals (Au, Al, Ti,…)
- Dielectrics (Ge, Si, Te,…)
- Photoconductors
- Any evaporatable material

Matrix Material

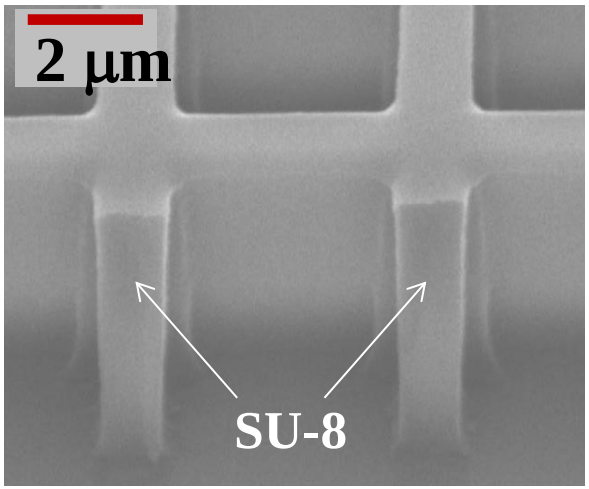
- SU-8
- Polynorbornene
- Si
- Polaritonics

Material set for matrix, membrane and backfill must form a process-orthogonal set

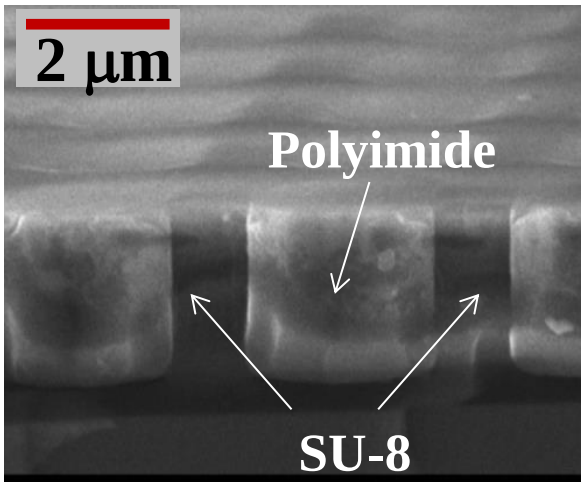
Organic MPL Process Flow



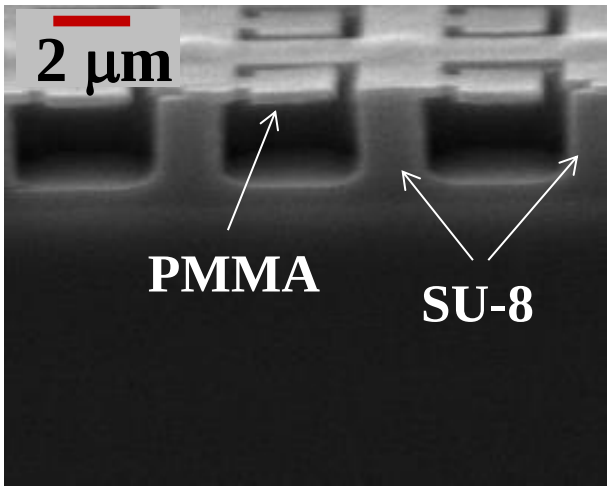
Create Cavity | Sacrificial Backfill | Planarize Backfill | Deposit/Pattern Membrane | Dissolve Out Backfill | Directional Processing



Create Cavity

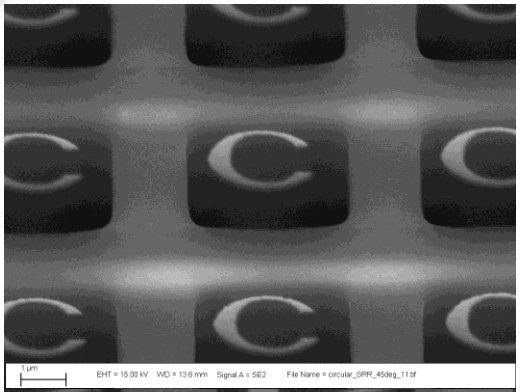


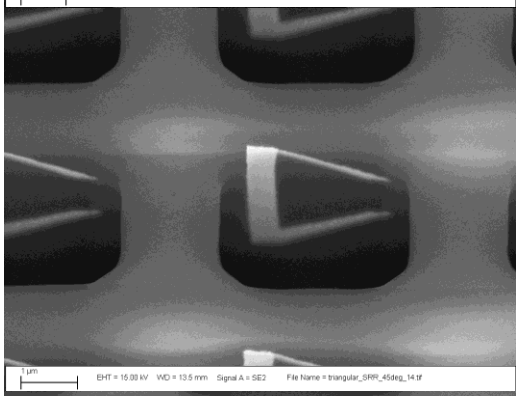
Planarize Backfill

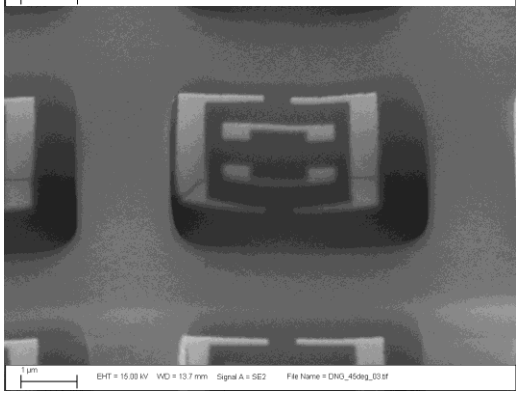


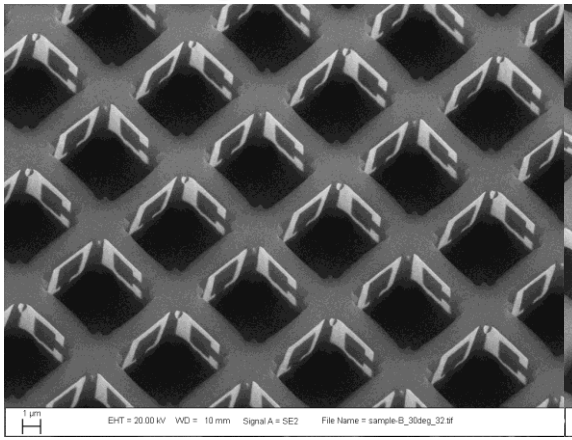
Dissolve Out Backfill

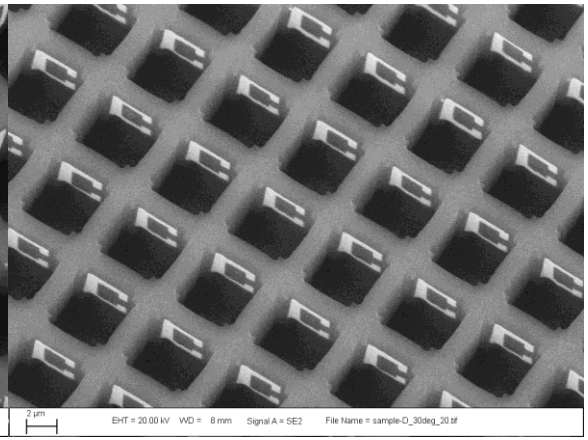
Micron-Scale Cubic Metamaterial Layers

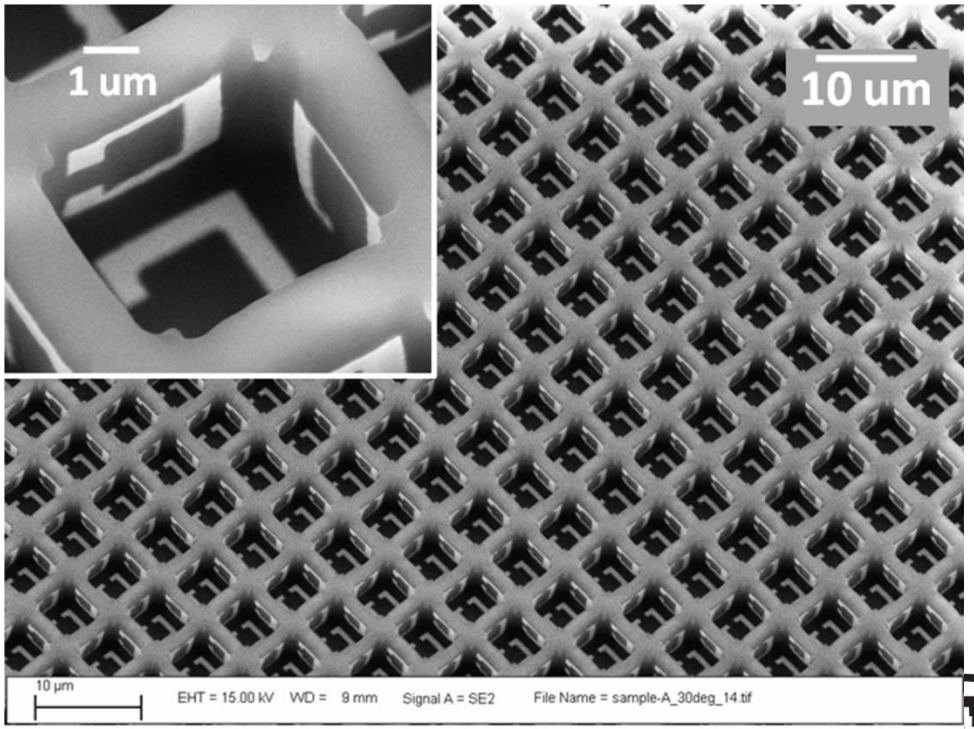












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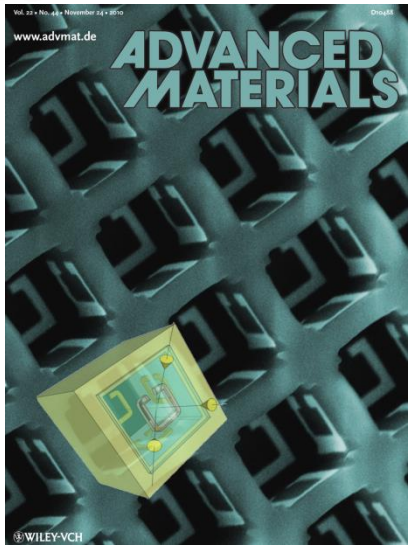
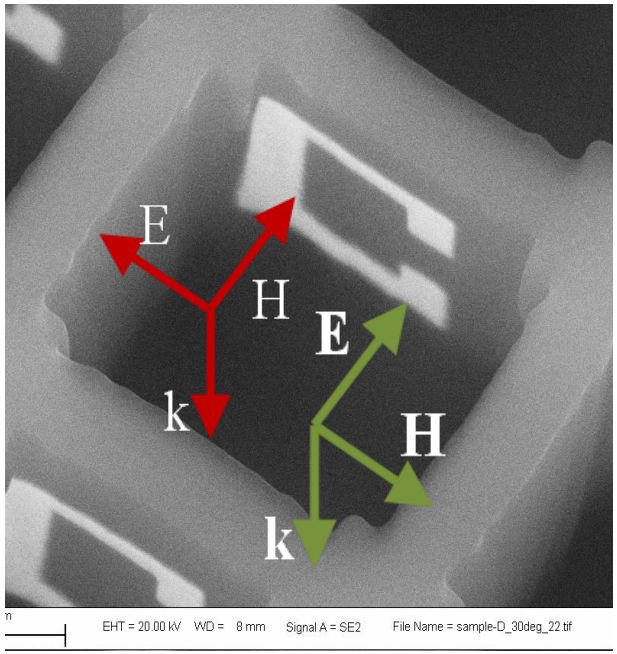
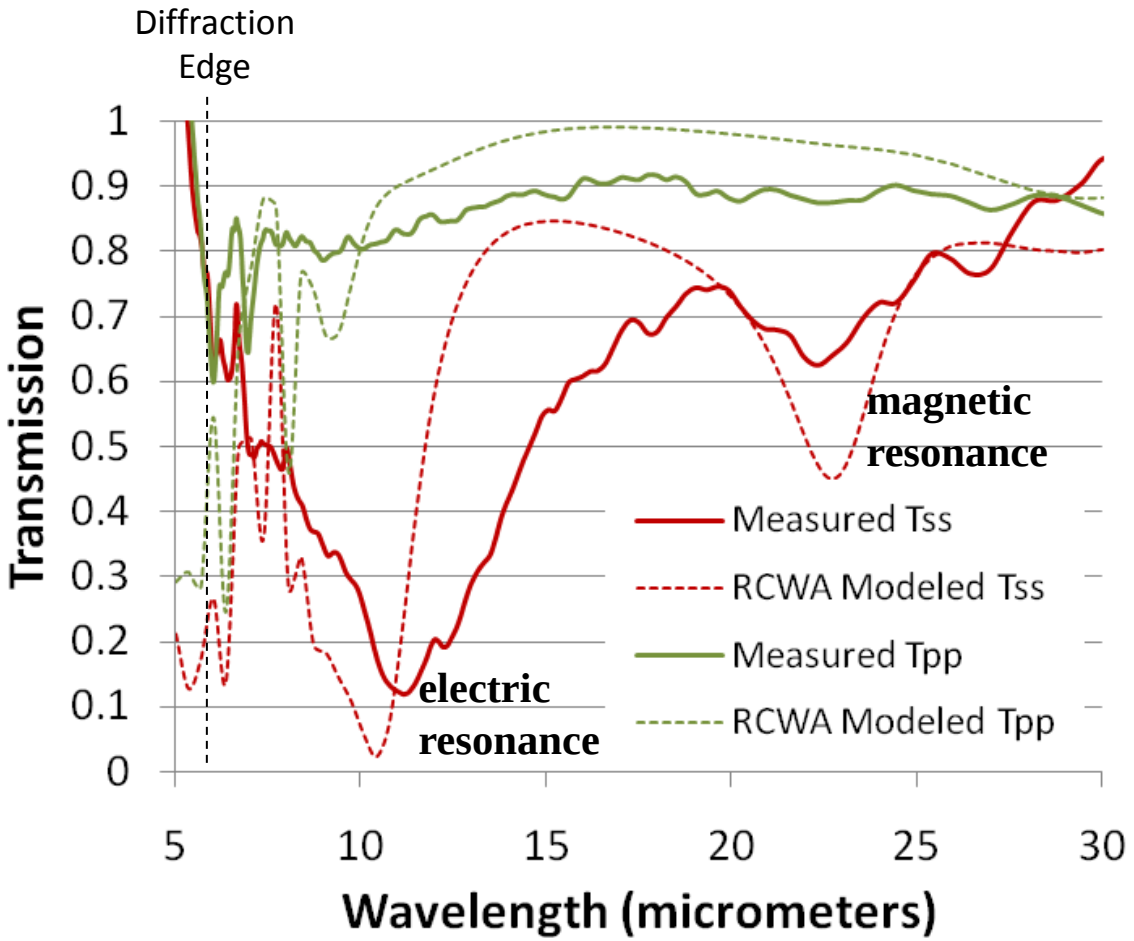
Demonstration of Magnetic Polarization in the IR







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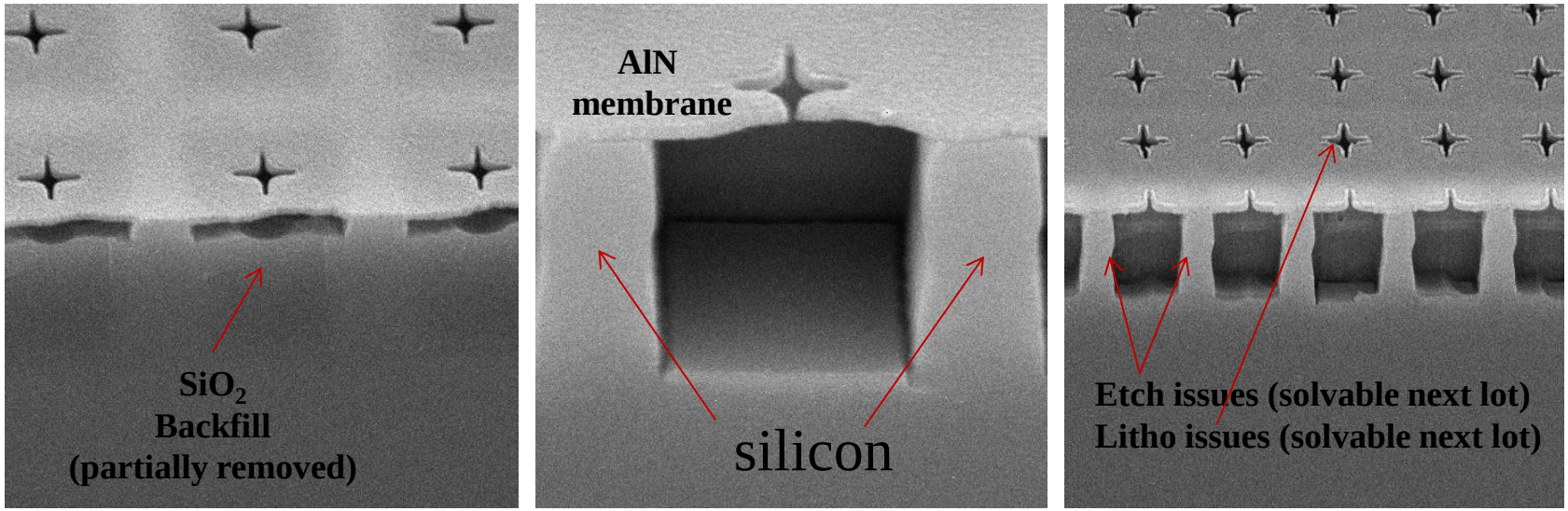
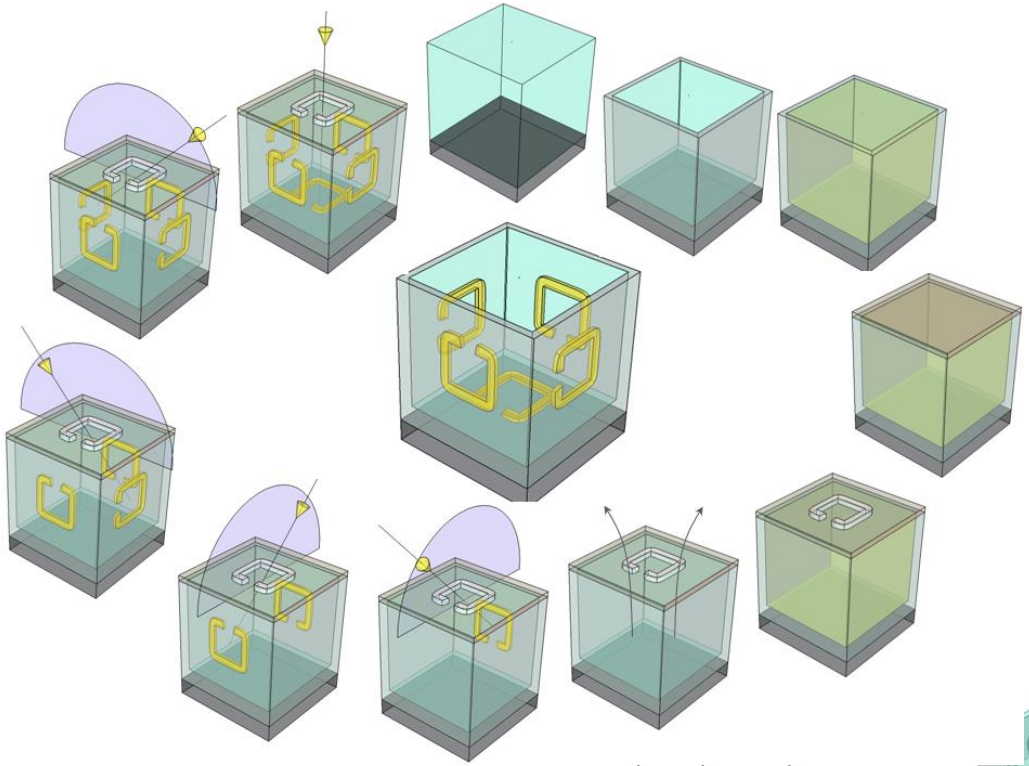
MPL : Inorganic Material Set

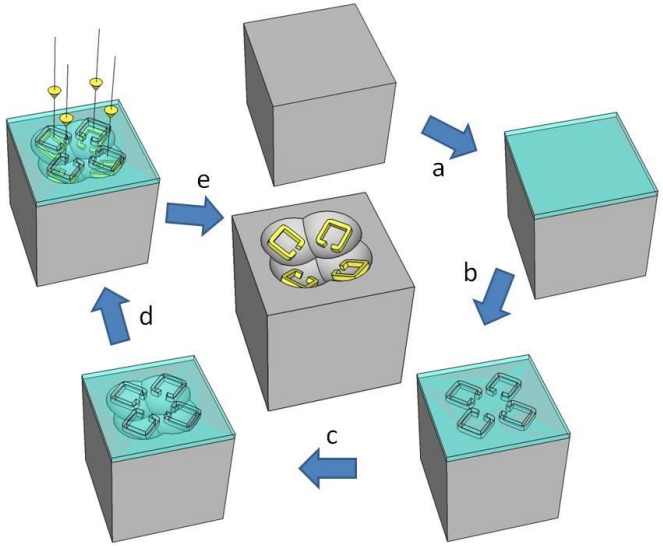


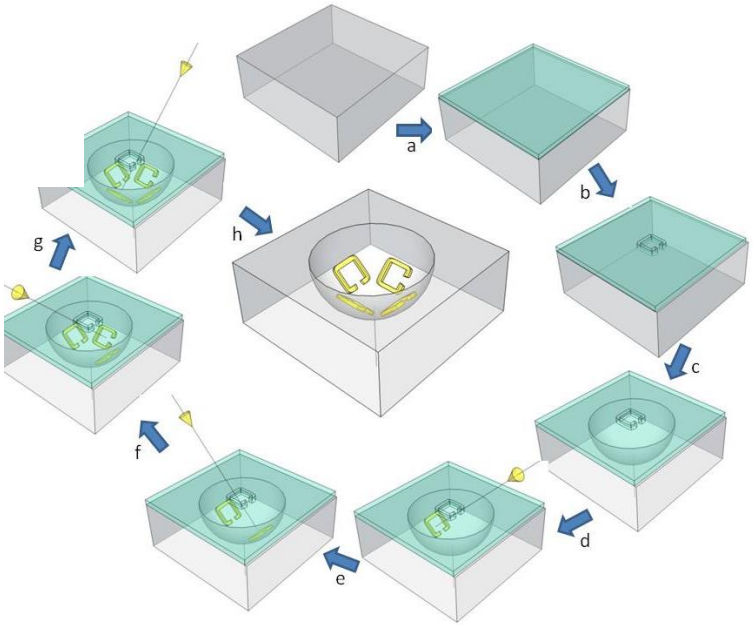
Lithography : Stepper
Inorganic backfill, CMP planarization

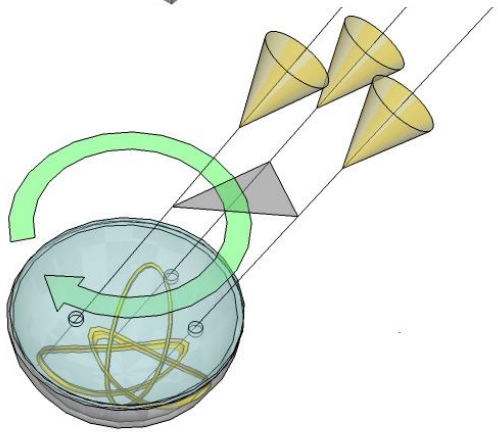
Subject of an upcoming LDRD : Fabrication of 3D Ics via MPL

MPL At A Glance









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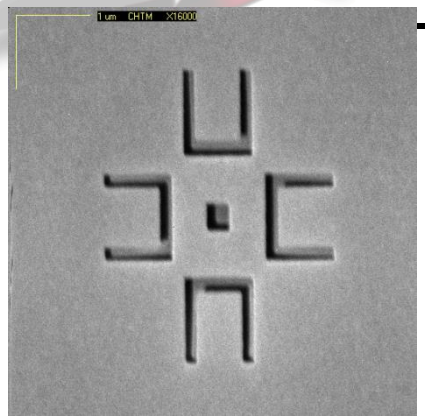
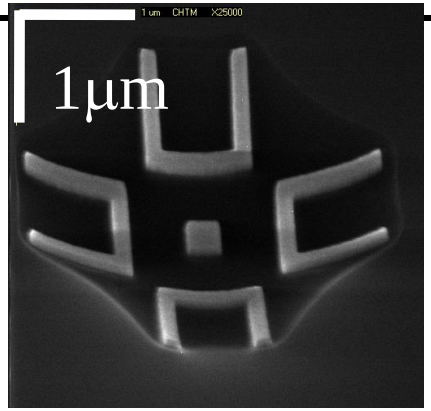
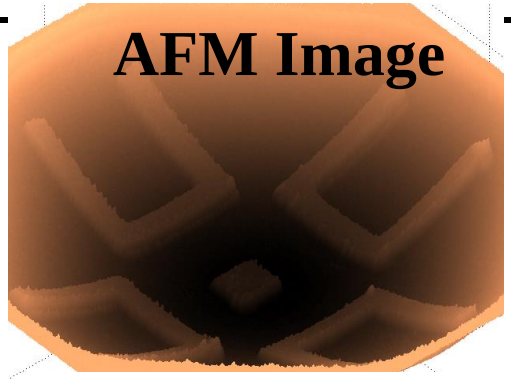
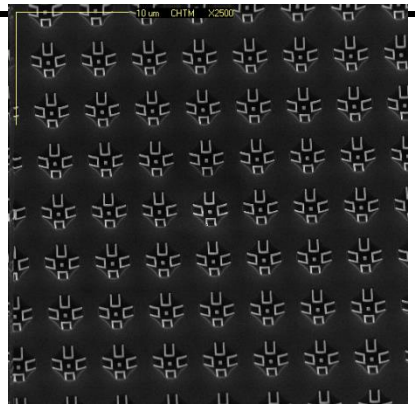
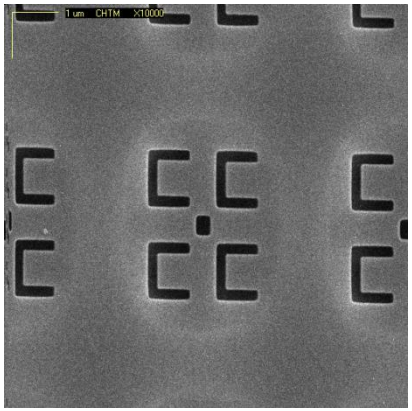
Examples of Single Evaporation SAMPL

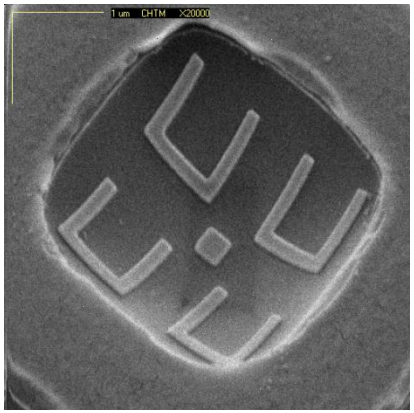


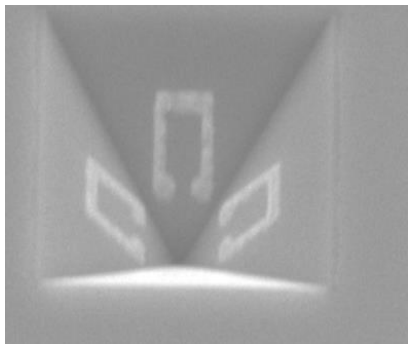


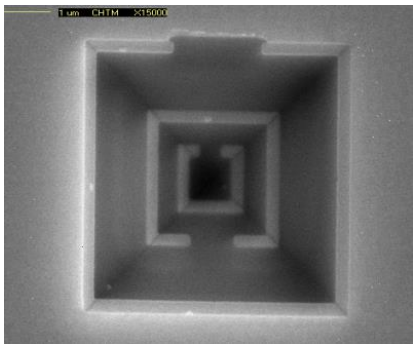




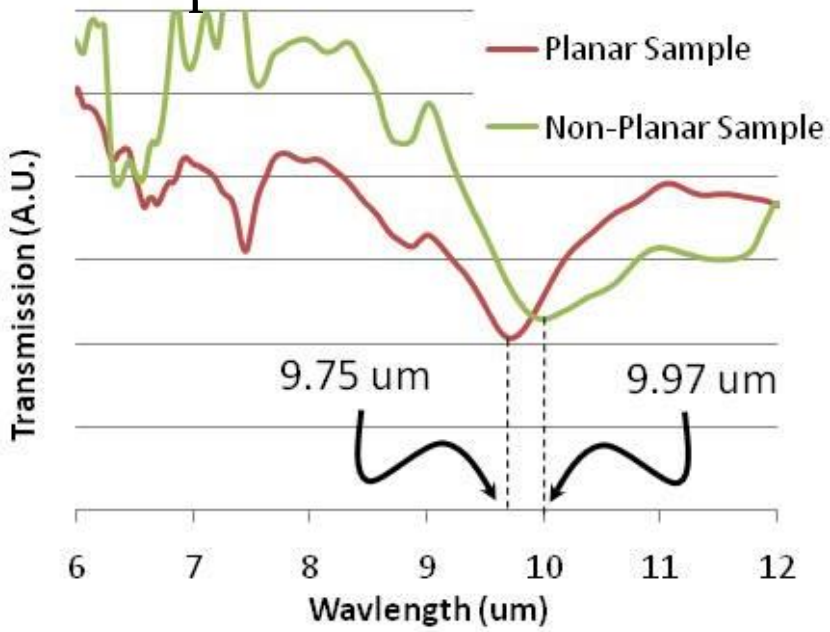








Resonators 20^0 out-of-plane



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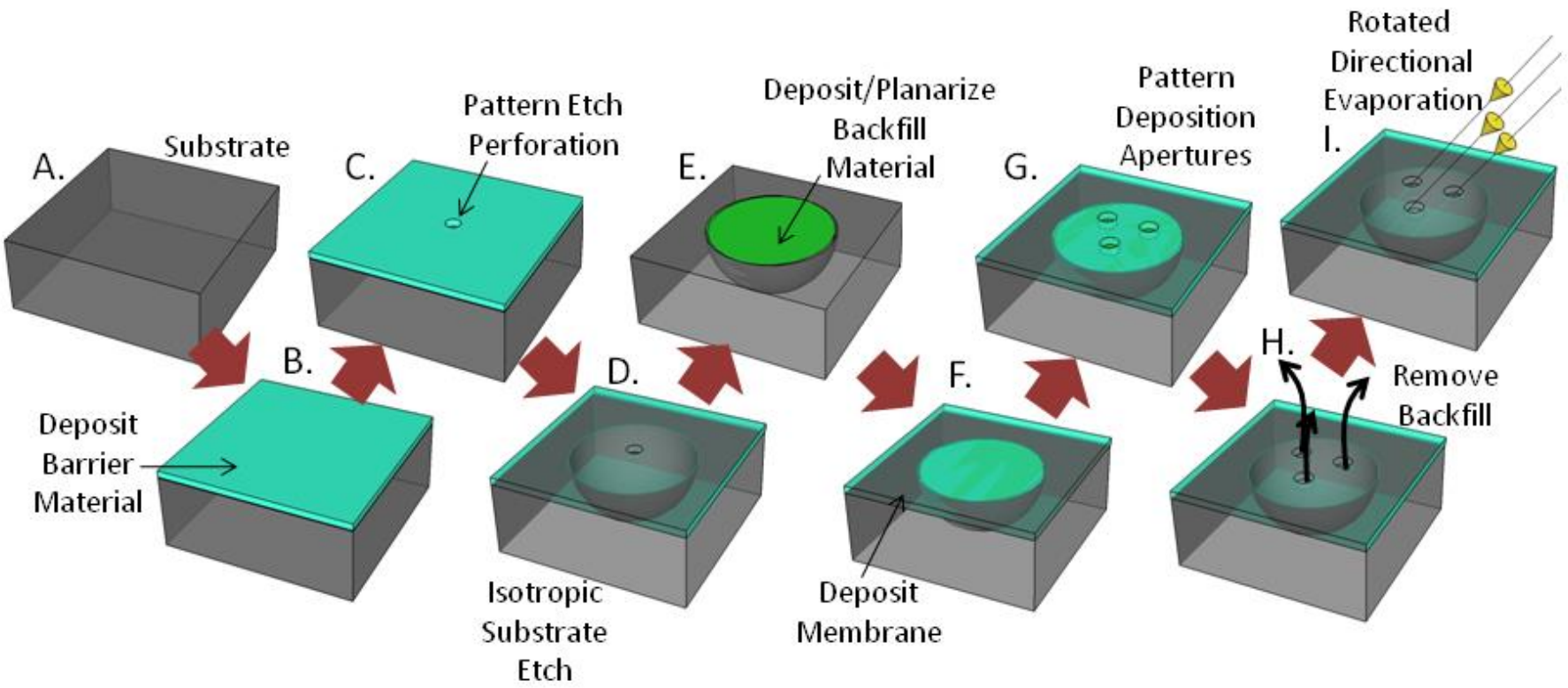
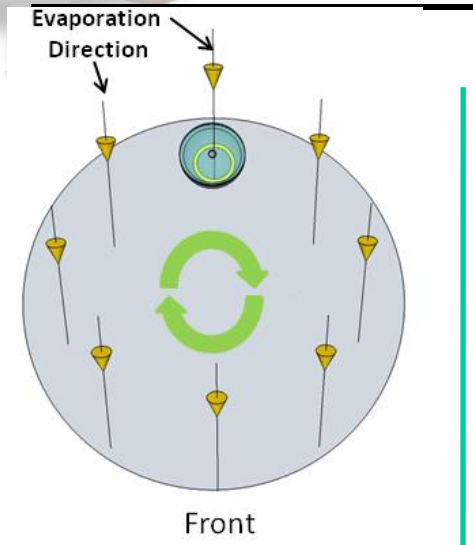
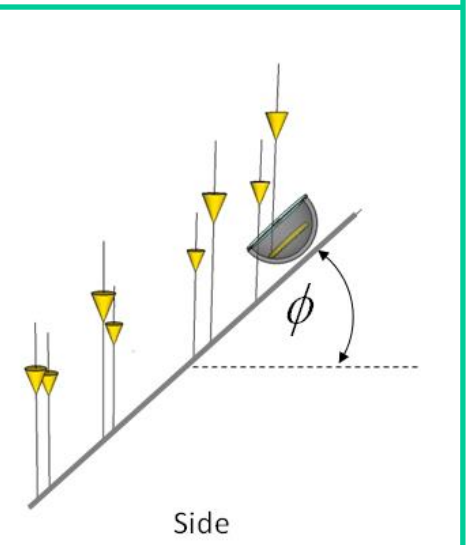
Two-Step Process Flow



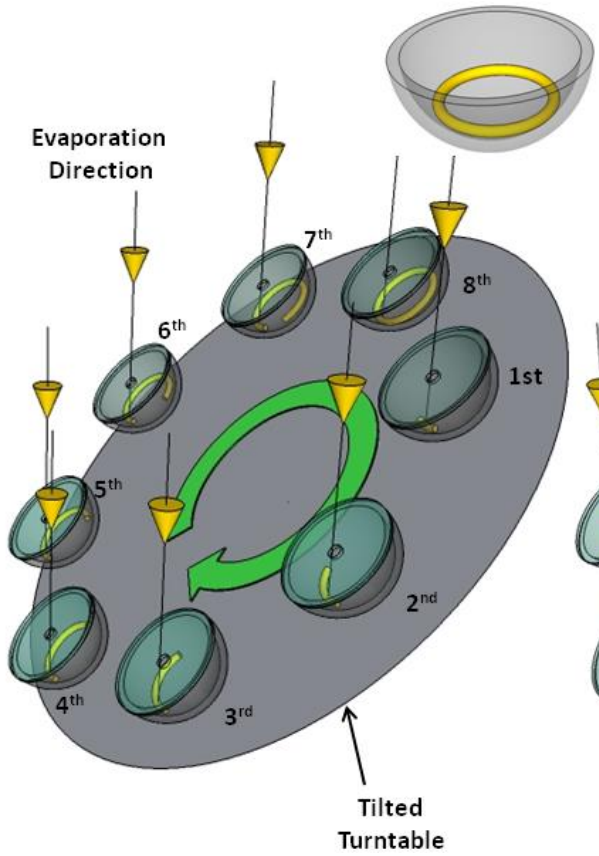
Cavity shape is now decoupled from perforation locations – wider variety of possible trace geometries.

A More Practical Fabrication Approach

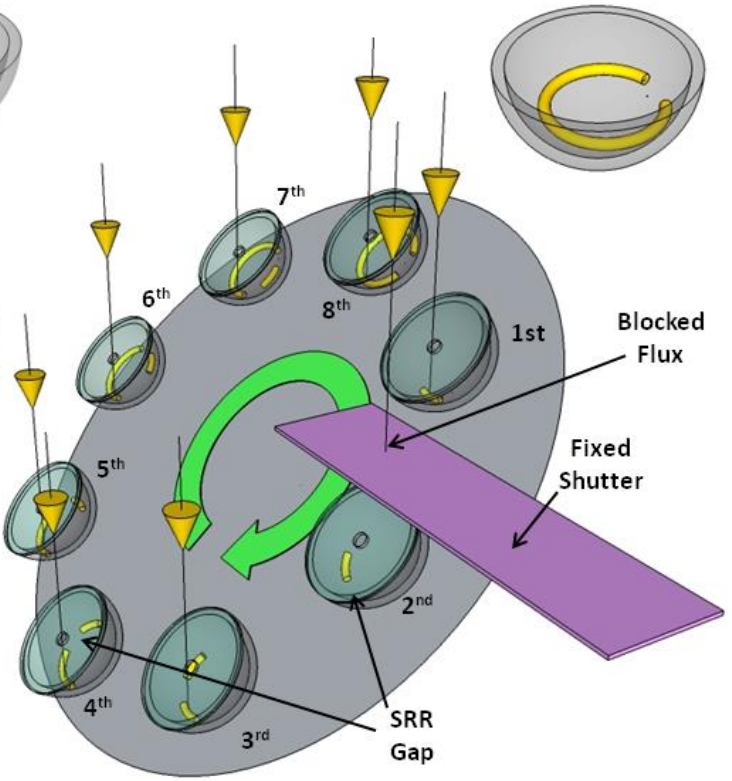




Closed Loops



Split Loops



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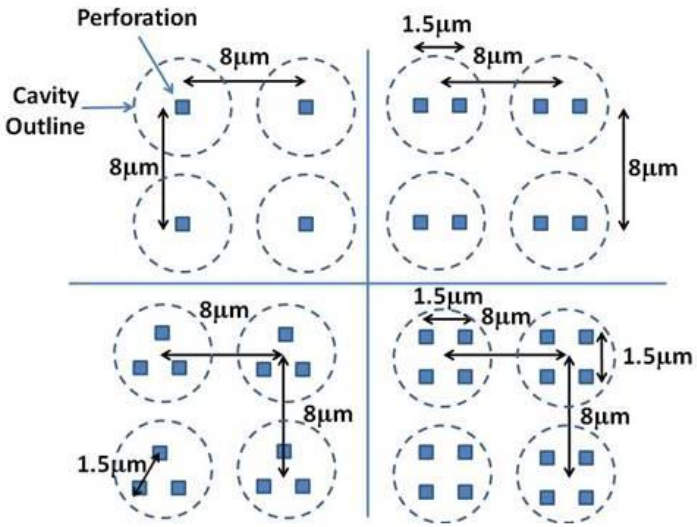
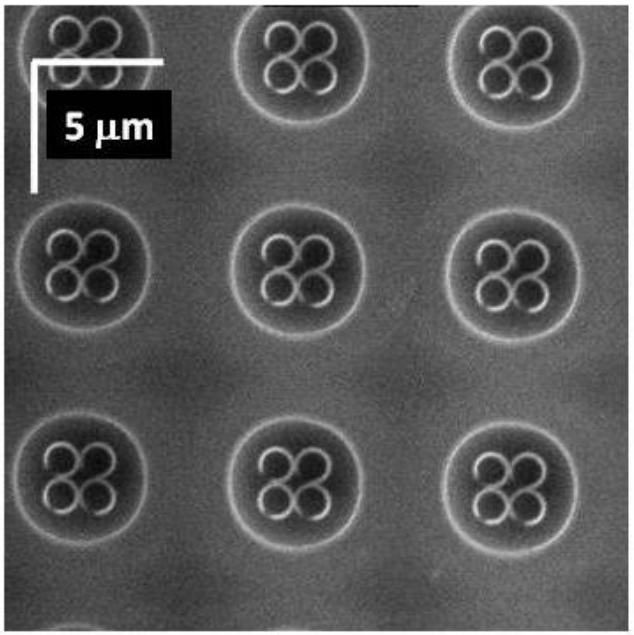
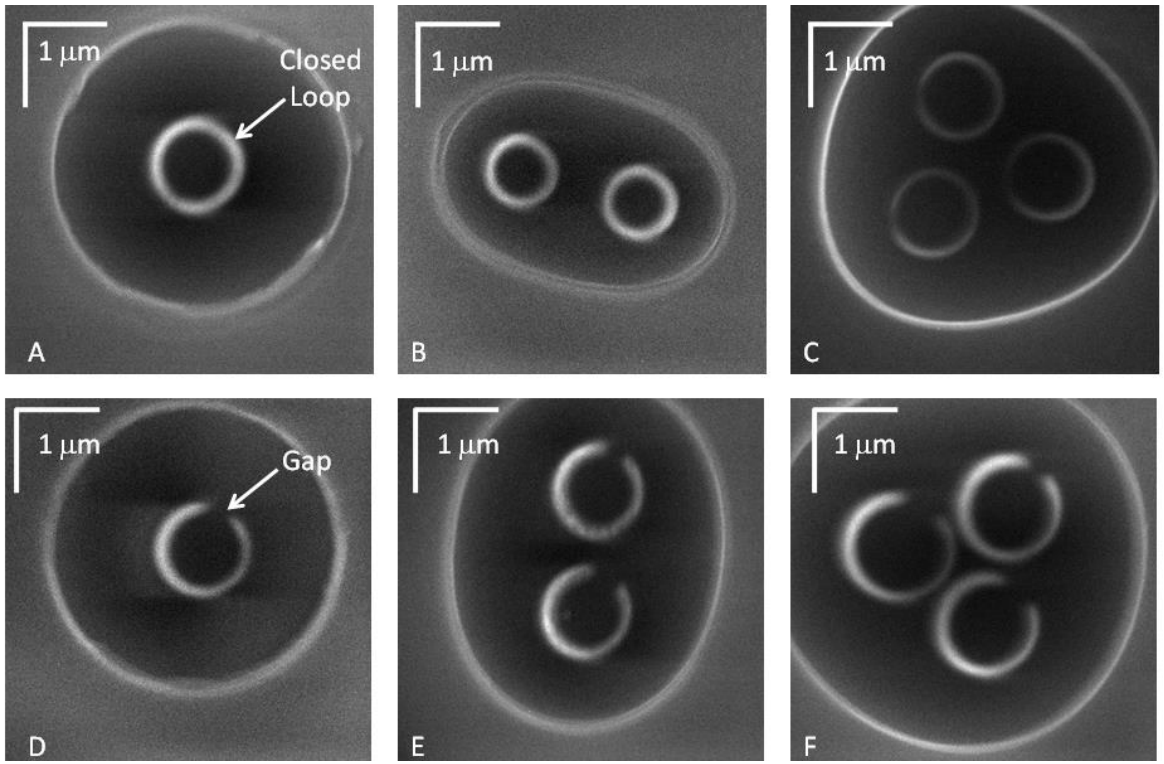
Preliminary Self- Aligned Fabrication Results





Self-aligned process flow – trace dependent cavity shape



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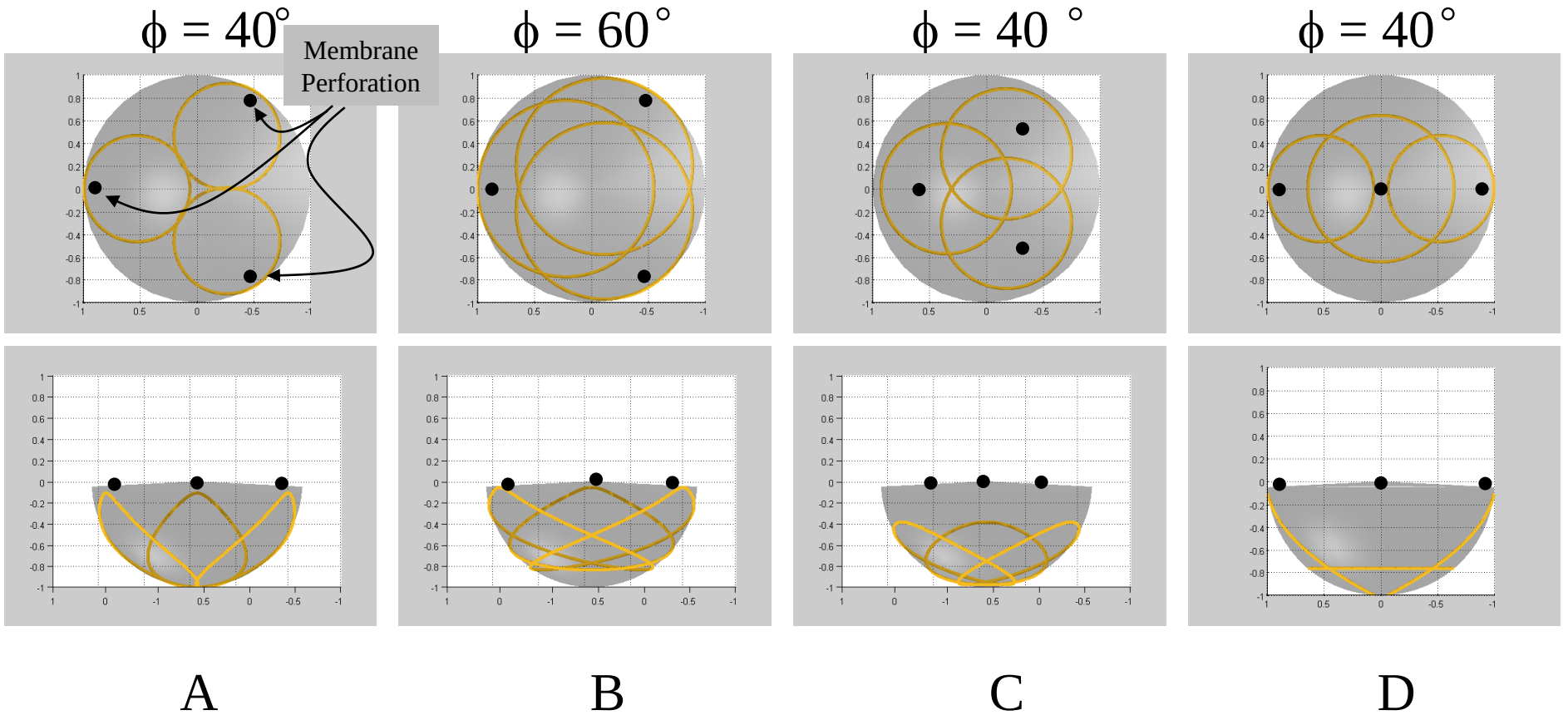
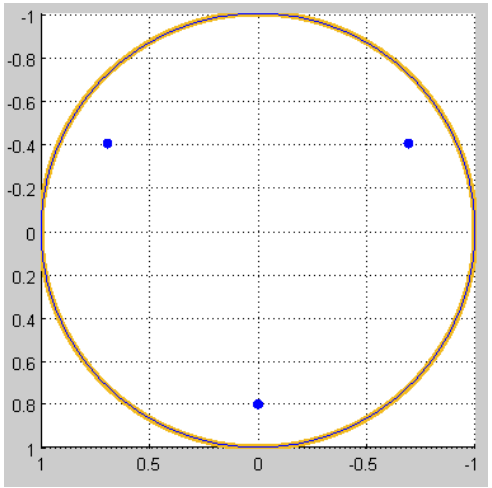
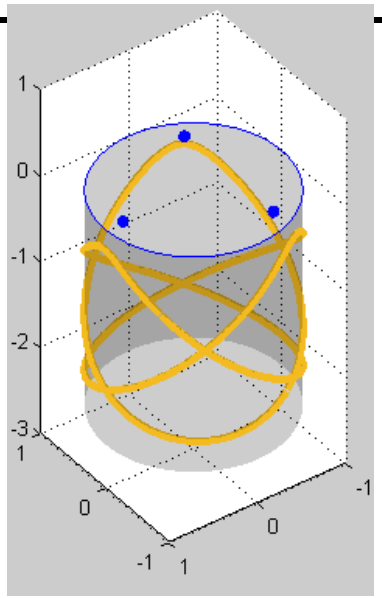
3D Multi-loop Traces

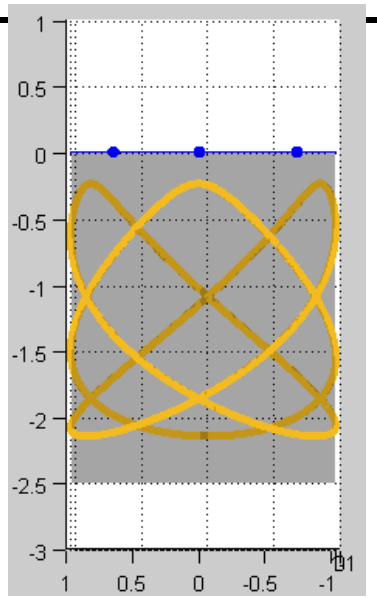


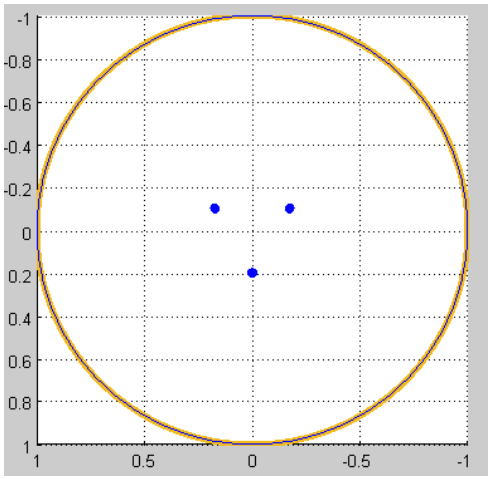
Simple geometrical variations lead to highly diverse 3D trace geometries

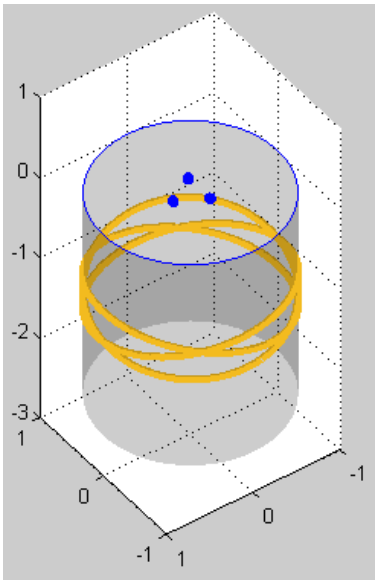
Dynamic MPL in a Cylindrical Cavity

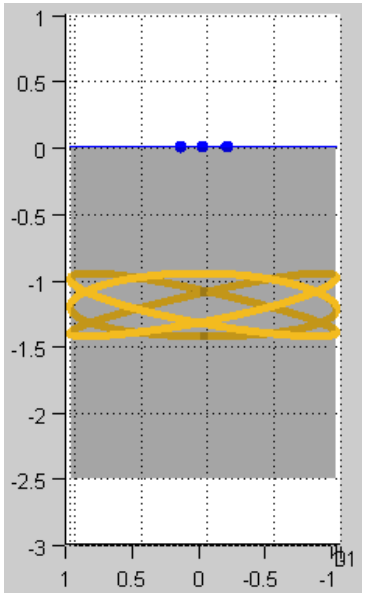












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MPL Fabrication Parameter Space

Membrane Lithography

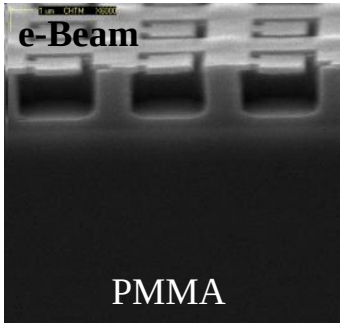
Membrane Material

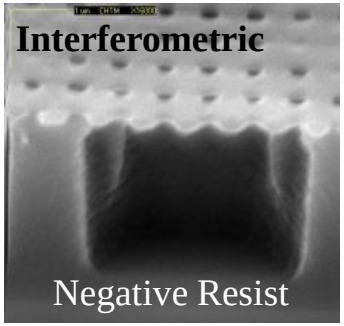
Inclusion shape

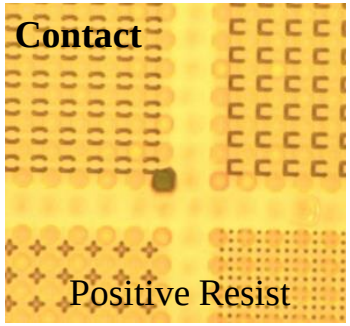
Resonance

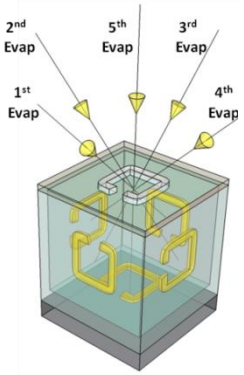
Matrix Material

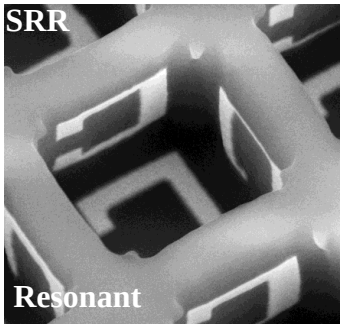
Cavity Shape

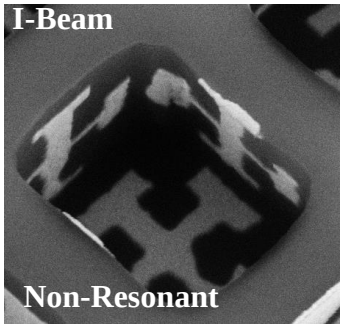


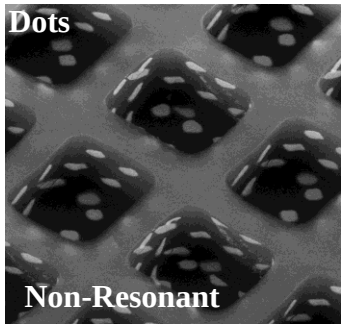


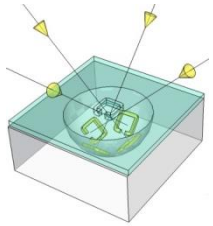


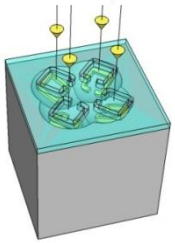


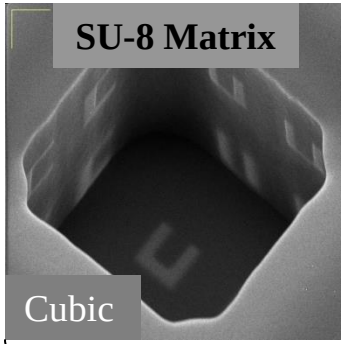


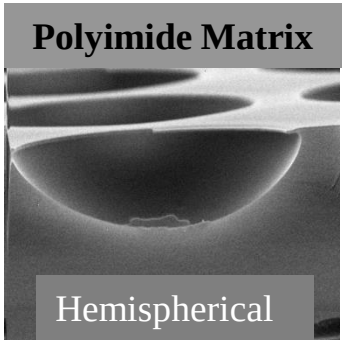


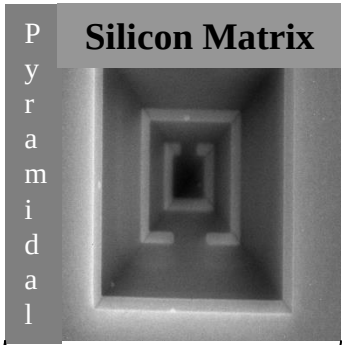


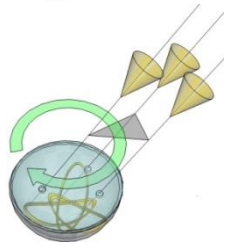












Organic

Inorganic

Sandia National Laboratories

Conclusions

1.) Membrane projection lithography is a manufacturable route to micron-scale 3D metamaterials.
2.) Identification of a process-orthogonal material set is critical to success of MPL.
3.) Fabrication in 3D opens a wide parameter space of potential unit cell design possibilities.
4.) CMOS compatible MPL should open a wide range of new applications.

Questions?