SAND2013-4604C

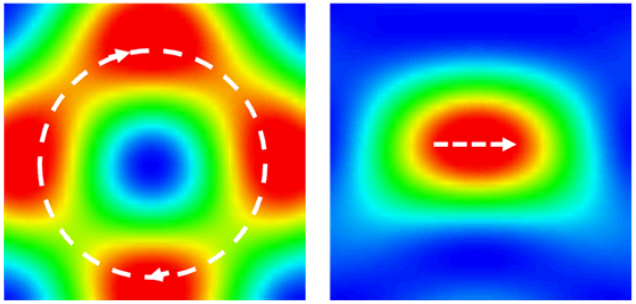
Realization of Tellurium-based all Dielectric Optical Metamaterials using a Multi-cycle Deposition-etch Process

Sheng Liu,[1,2,*] Jon F. Ihlefeld, [1] Jason Dominguez, [1] Edward F. Gonzales,[1,2]John Eric Bower,[1] Bruce D. Burckel,[1] Michael B. Sinclair,[1] Igal Brener[1,2]

[1]*Sandia National Laboratories*

[2]*Center for Integrated Nanotechnologies, Sandia National Laboratories*

[*]*snliu@sandia.gov*



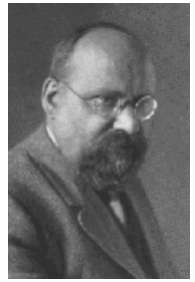
Appl. Phys. Lett. **102**, 161905 (2013); http://dx.doi.org/10.1063/1.4803019

This work was performed, in part, at the Center for Integrated Nanotechnologies, a U.S. Department of Energy, Office of Basic Energy Sciences user facility. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Dielectric Mie Resonators

http://www.philiplaven.com/mieplot.htm

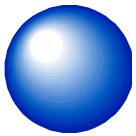
Gustav Mie



THE ELECTRICAL CONSTANTS OF A MATERIAL LOADED WITH SPHERICAL PARTICLES*

By L. LEWIN.†

(*The paper was first received 4th March, and in revised form 27th September*, 1946.)



magnetic activity (negative permeability) can be achieved:

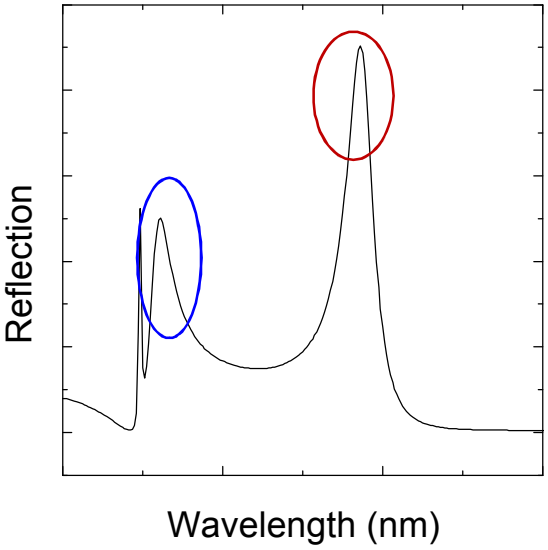
$$-\frac{2+f}{1-f} < \frac{2(sin\theta - \theta cos\theta)}{(\theta^2-1)sin\theta + \theta cos\theta} < -2\frac{1-f}{1+2f}.$$

First (Primary) resonance is magnetic for most materials; Secondary is electric

$\theta = k_0 a\sqrt{\varepsilon_i}$

$f = \frac{4\pi a^3}{3s^3}$

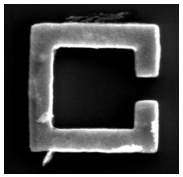
a is the radius of the sphere
s is the sphere's period
k_0 is the vacuum wavenumber
ε_i is the permittivity of the inclusion

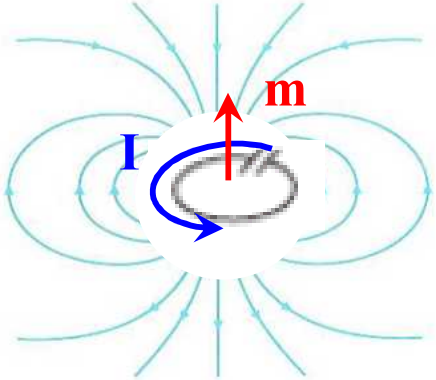


Control of Permittivity & Permeability

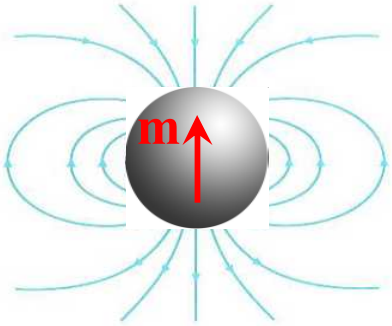
Metal vs Dielectric Resonators

Metallic Resonators





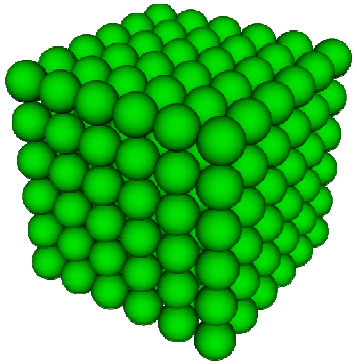
Dielectric Resonators



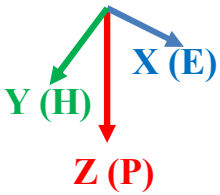
Dielectric Resonators: Low loss displacement currents replace lossy conduction currents

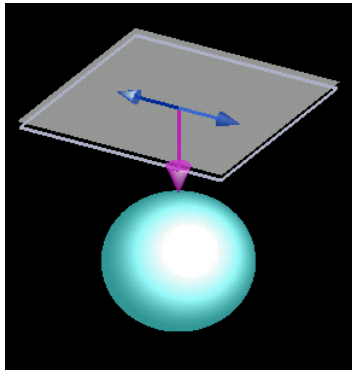
Dielectric Resonators: More isotropic response can be achieved

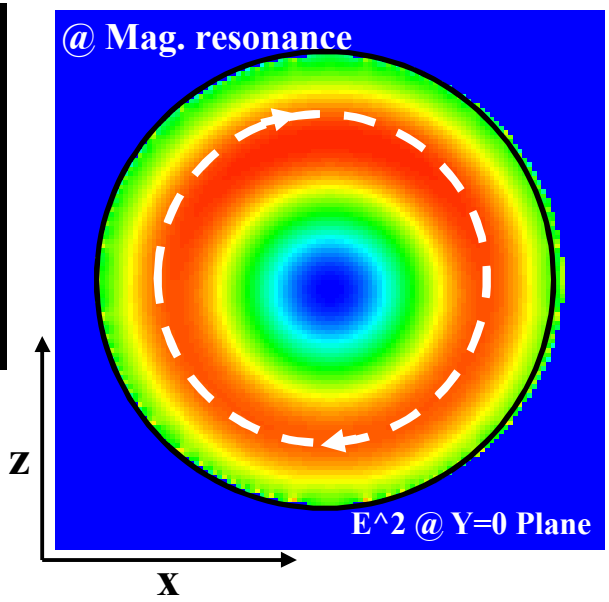
Dielectric Resonators: no established processing techniques for high permittivity materials

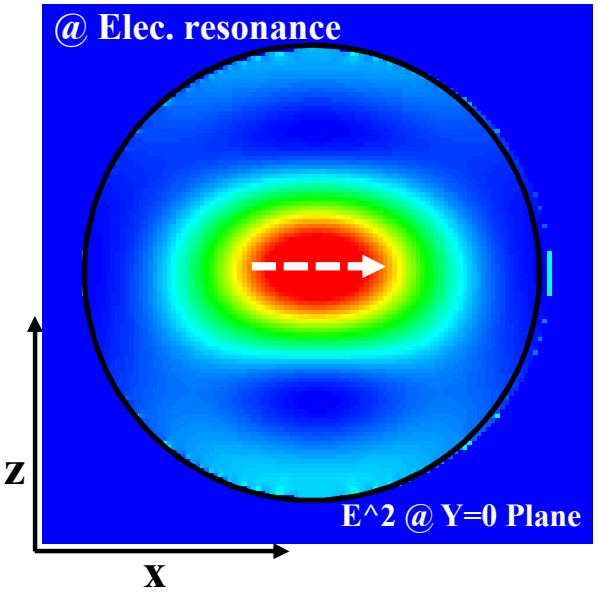


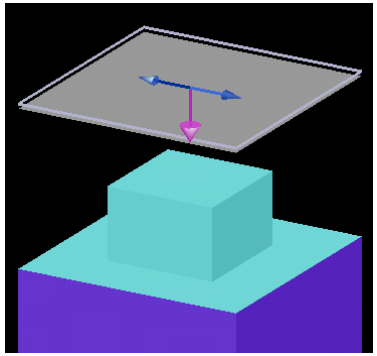
Lowest Two Mie Resonances for Sphere & Cube



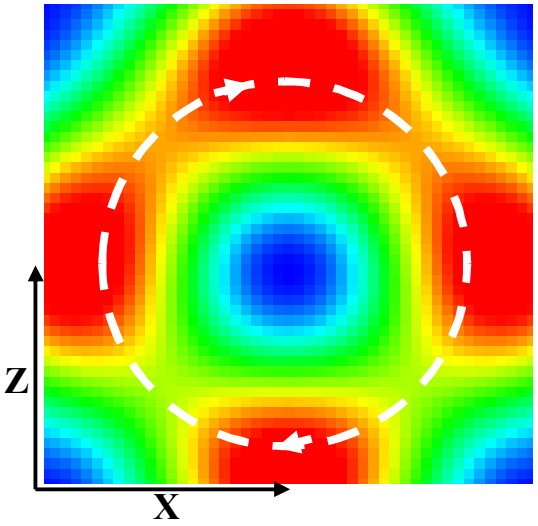




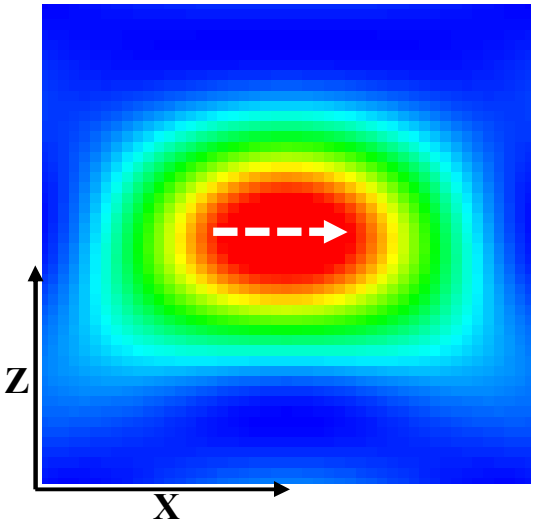




@ Mag. Resonance E^2 @ Y=0 Plane



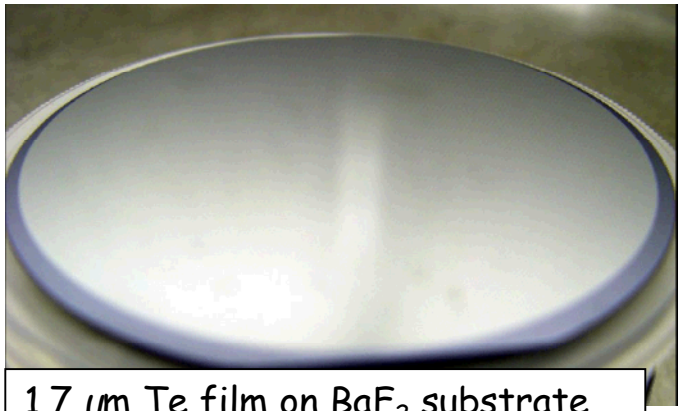
@ Elec. resonance E^2 @ Y=0 Plane



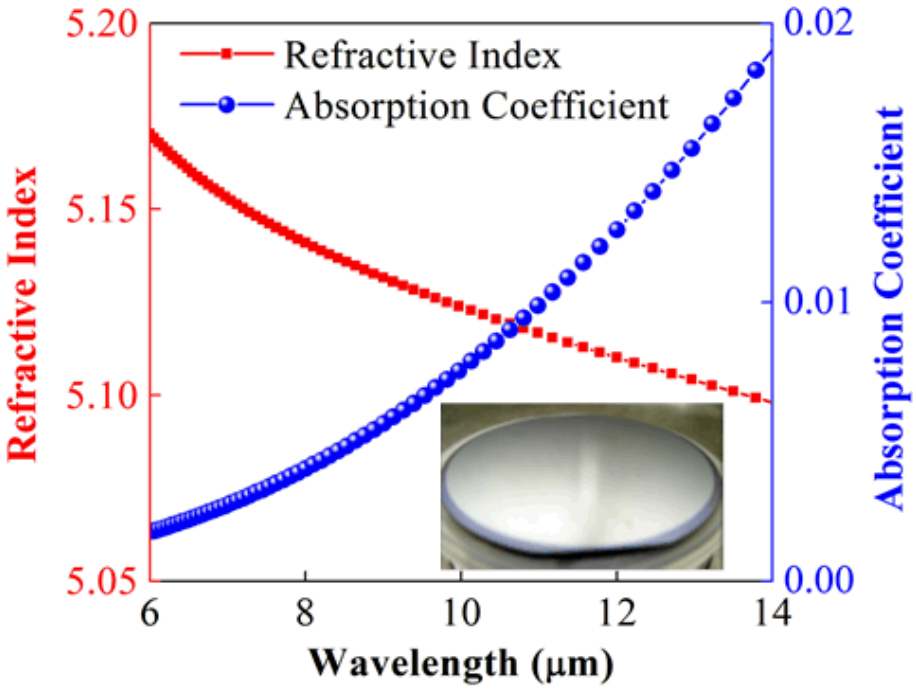
Electric field intensity profile

Dielectric Resonator Materials for the Thermal IR

- PbTe and Te are best choices for Thermal IR metamaterials (but Pb is problematic) because of high n
- Measured n = 5.1 + i0.01 @ 10 μm
- Selected BaF_2 as the substrate due to its low permittivity and high transparency from the visible to 10 μm



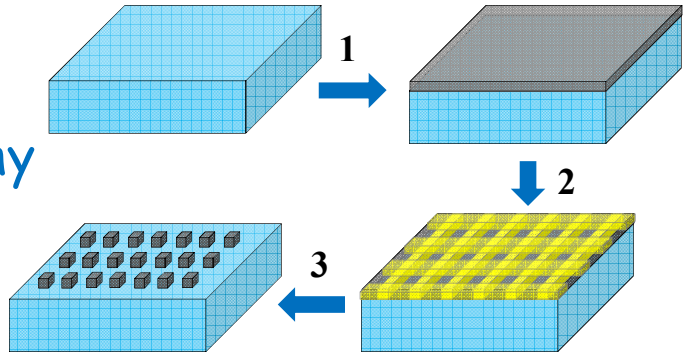
1.7 μm Te film on BaF_2 substrate



Fabrication of Cubic Dielectric Metamaterial

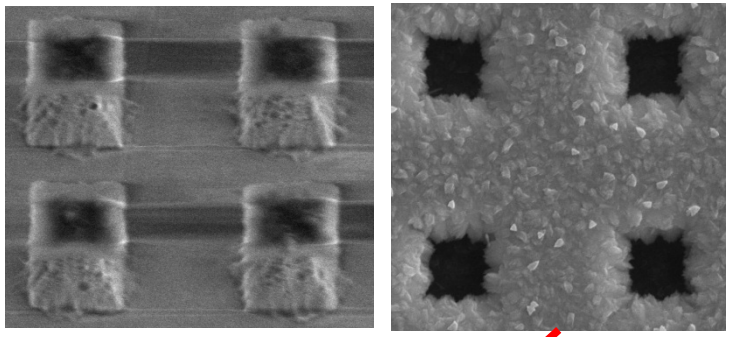
1. Deposition of Te on BaF_2
2. Patterned using E-beam lithography
3. Etching

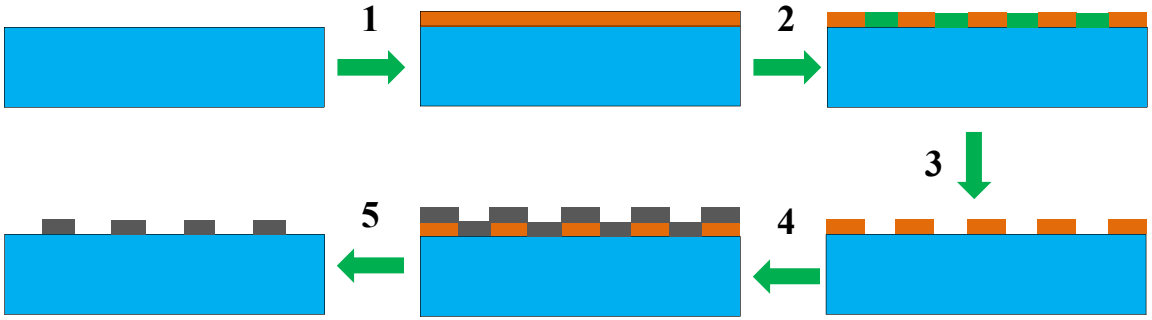
Undercutting

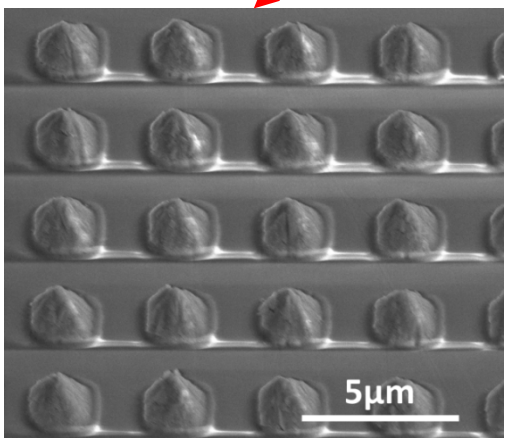


1. Spin photoresist (PMMA) on BaF_2
2. E-beam lithography
3. Developer solution
4. Deposition of Te
5. Lift-off

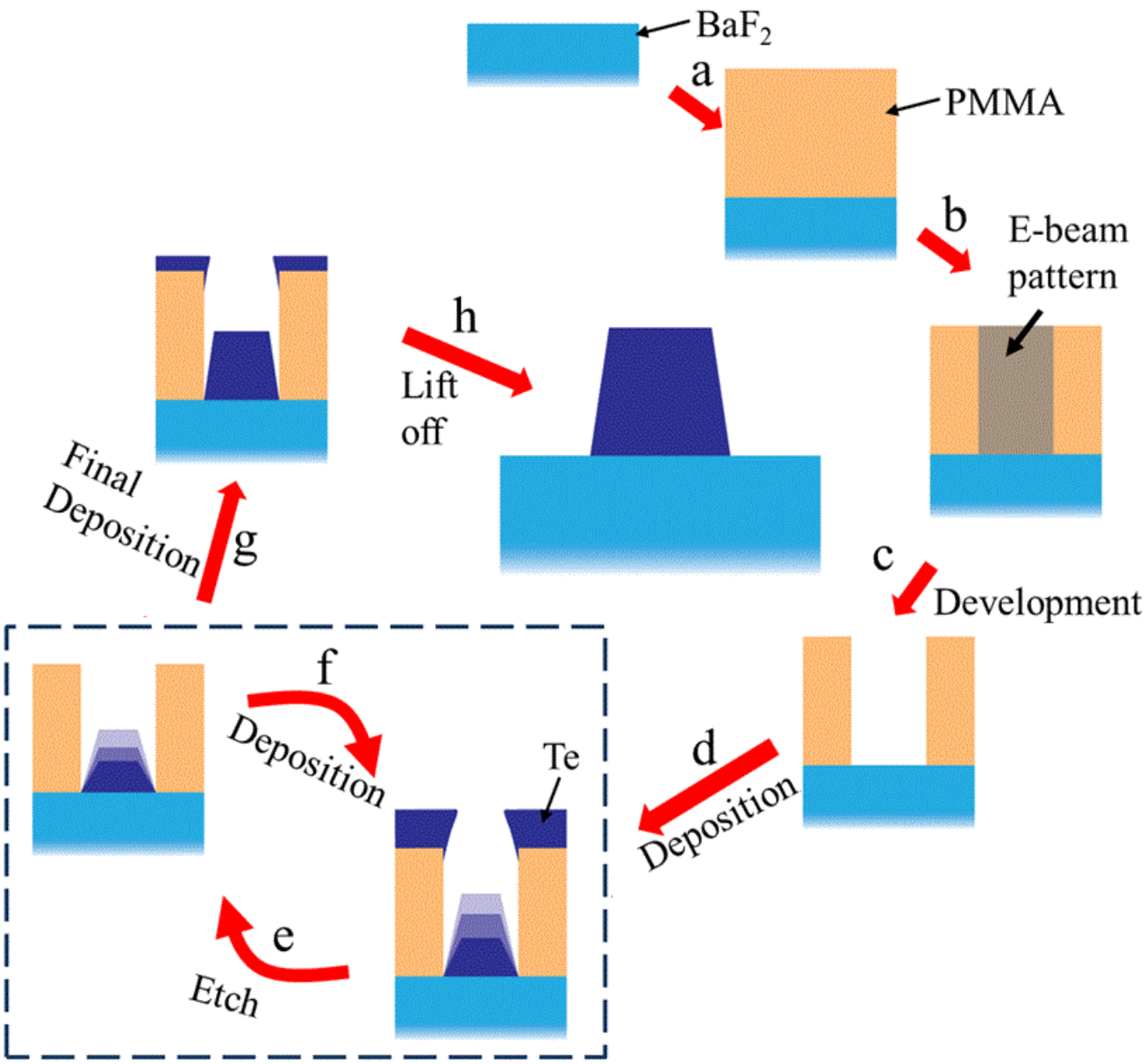
Pinch-off

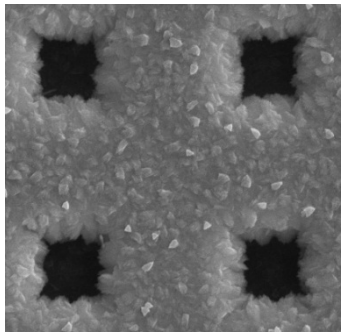


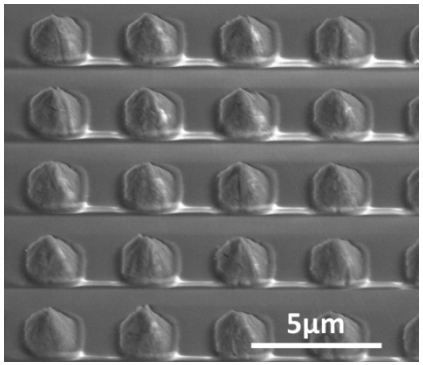




Multi-cycle Deposition-etch Process

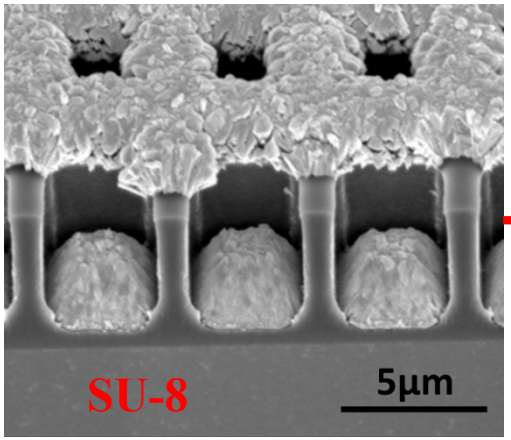




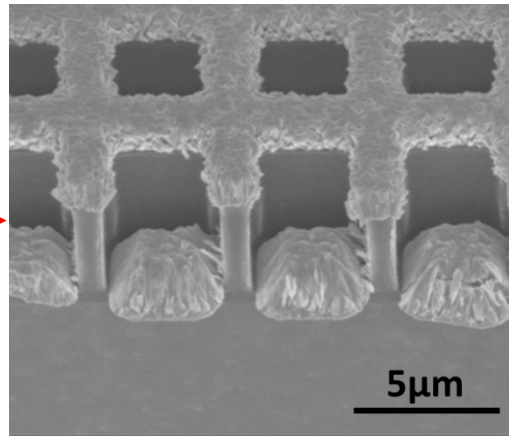


Pinch-off

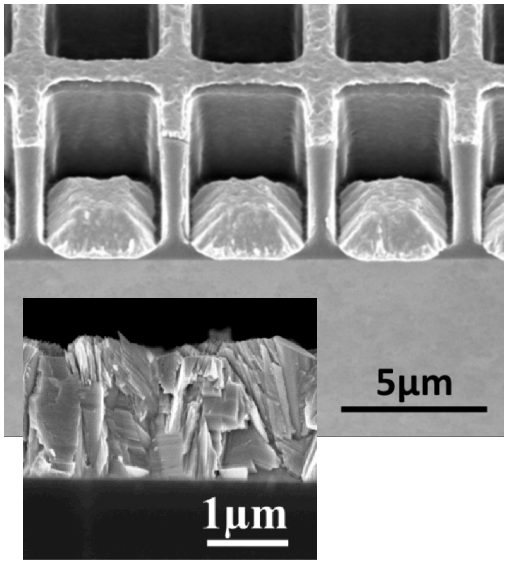
Multi-cycle Deposition-etch Process



1000s
RIE



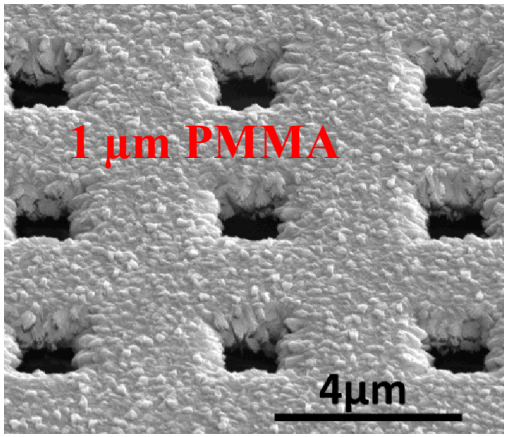
1000s
RIE

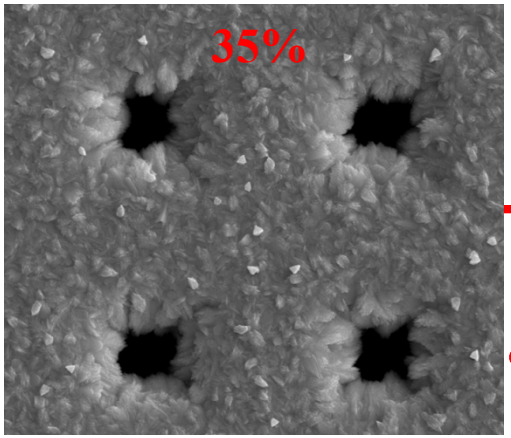


The cavity size is 4 X 4 X 4 µm.

Reactive Ion Etch

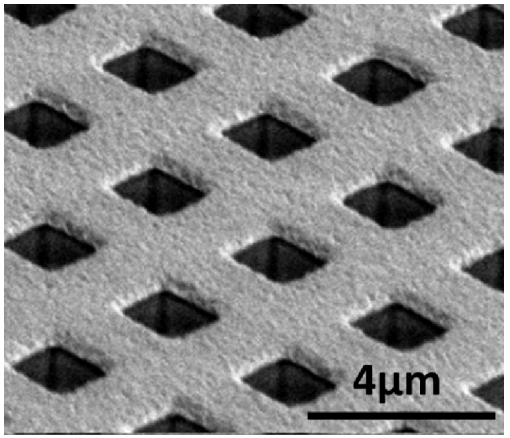
polycrystalline grain structure morphology with faceted grain surfaces





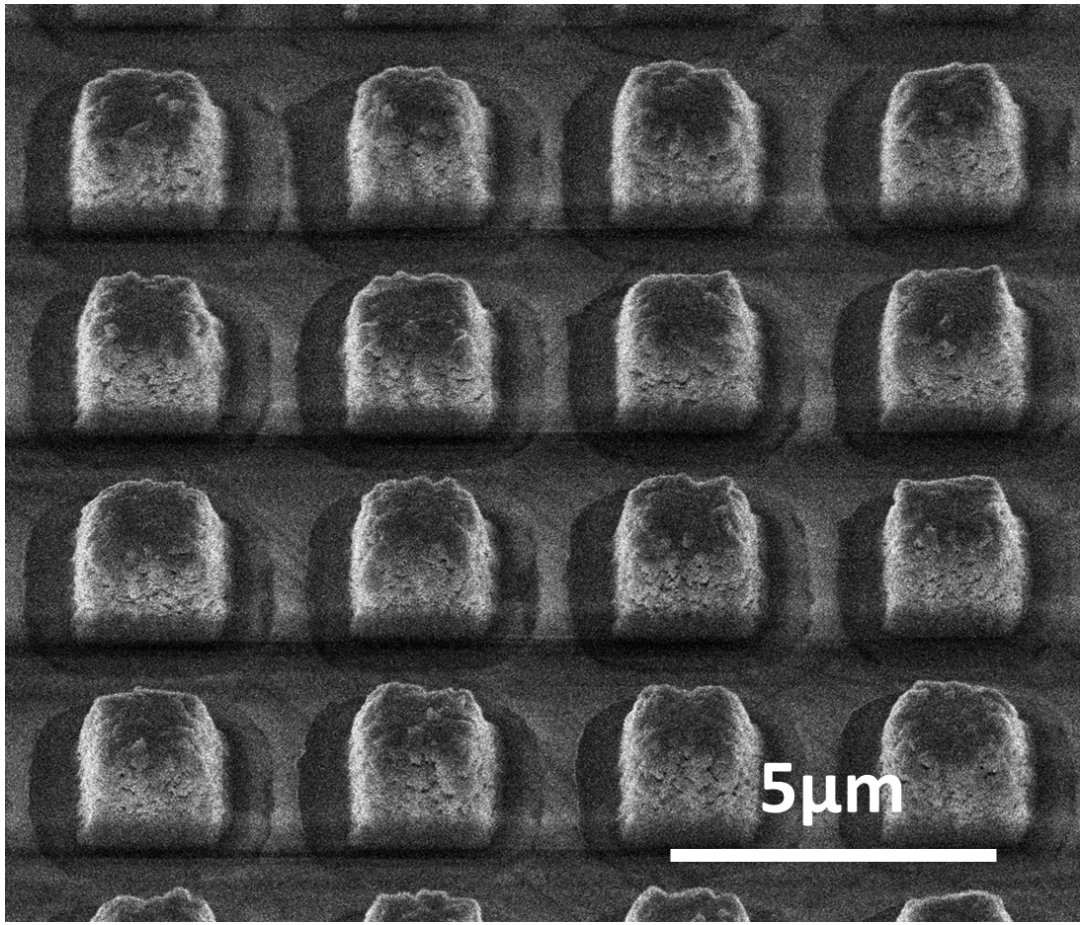
800s
RIE

Dep-etch
cycles

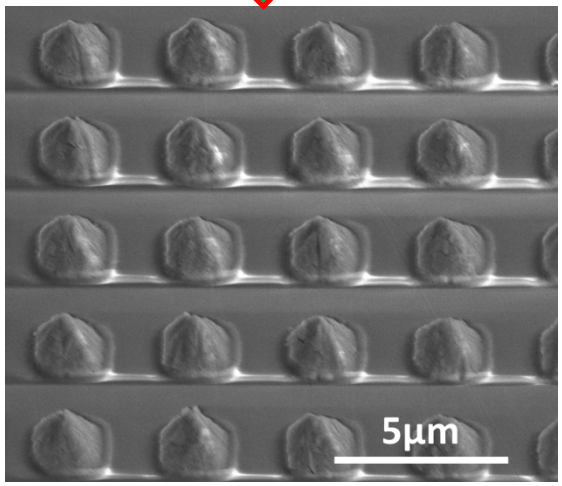


Multi-cycle Deposition-etch Process

Dep-etch cycles

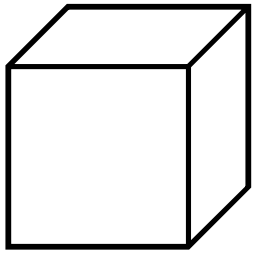


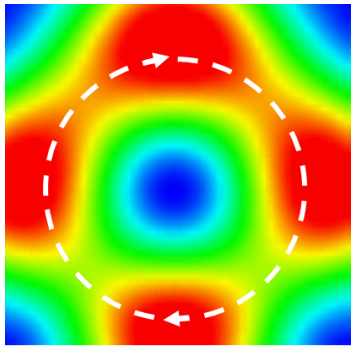
1 time deposition

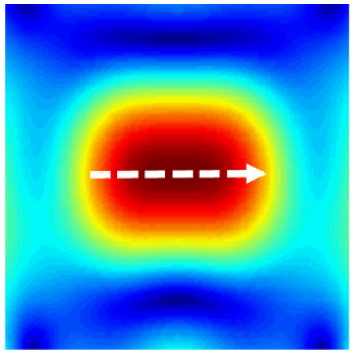


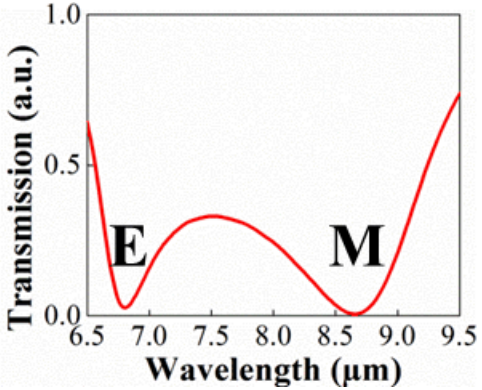
"Non-cubic" shape resonator

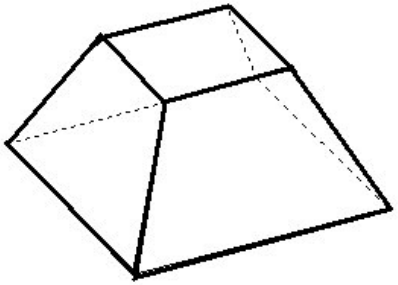
Perfect cube



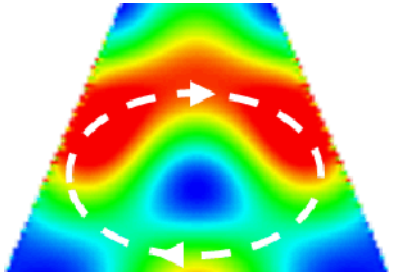


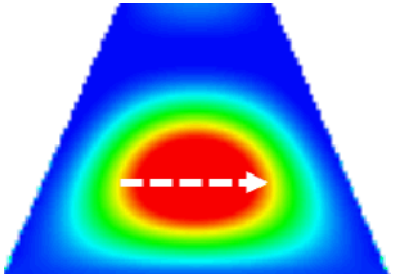


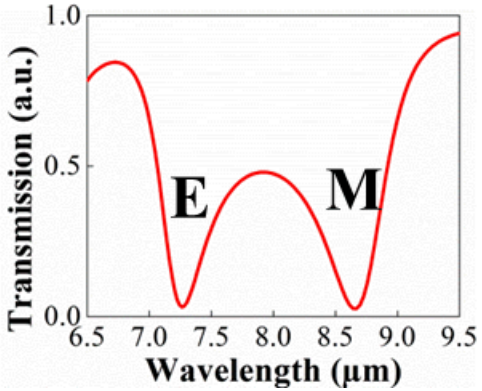




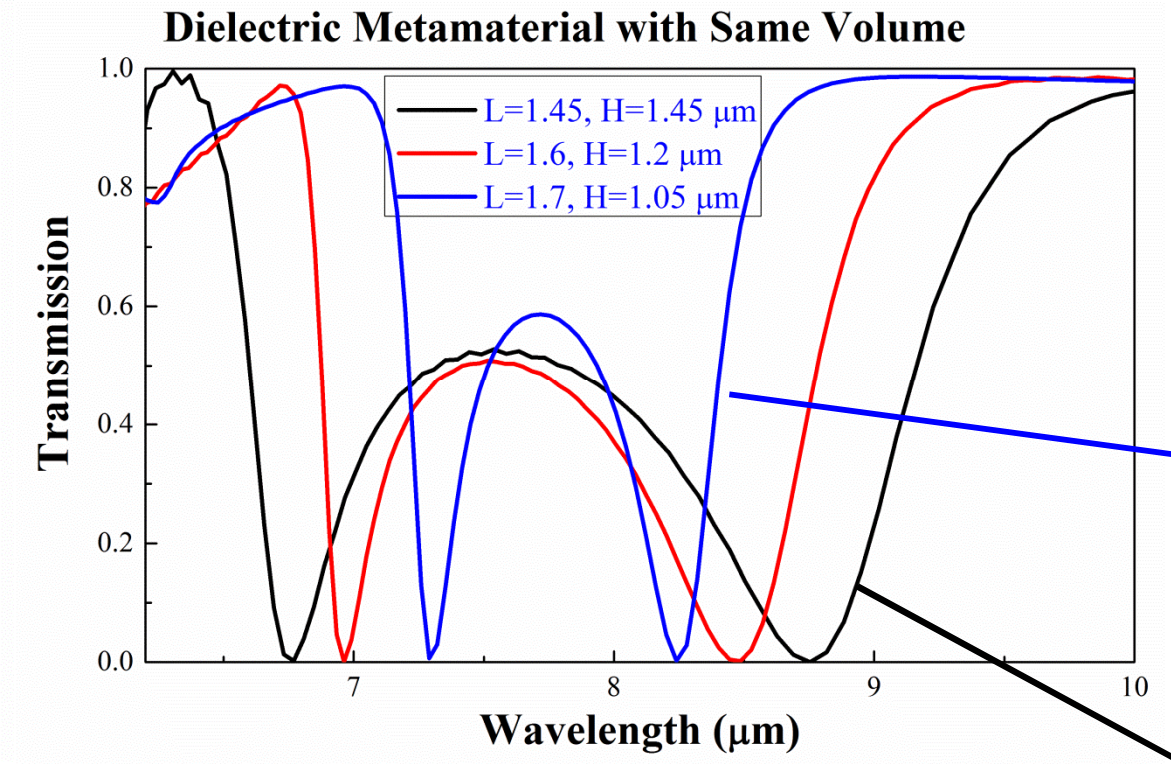
Pyramidal Frustum



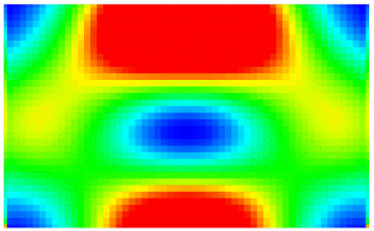


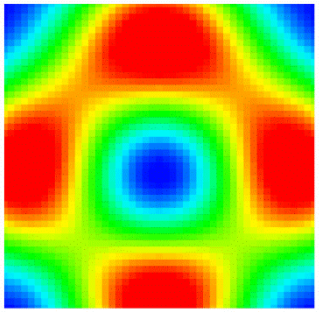


"Non-cubic" shape resonator—short cube

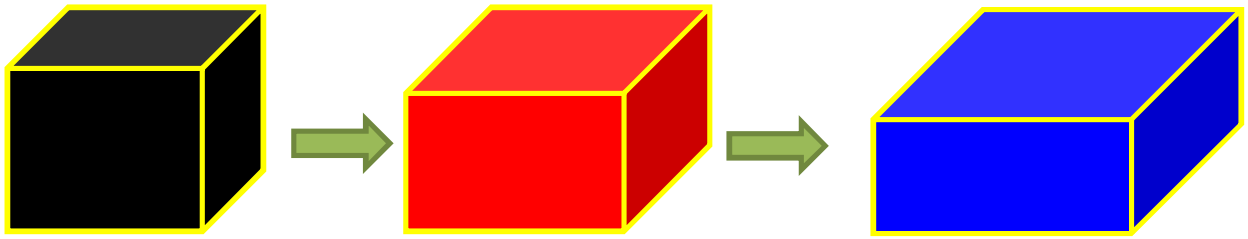


Displacement current loop





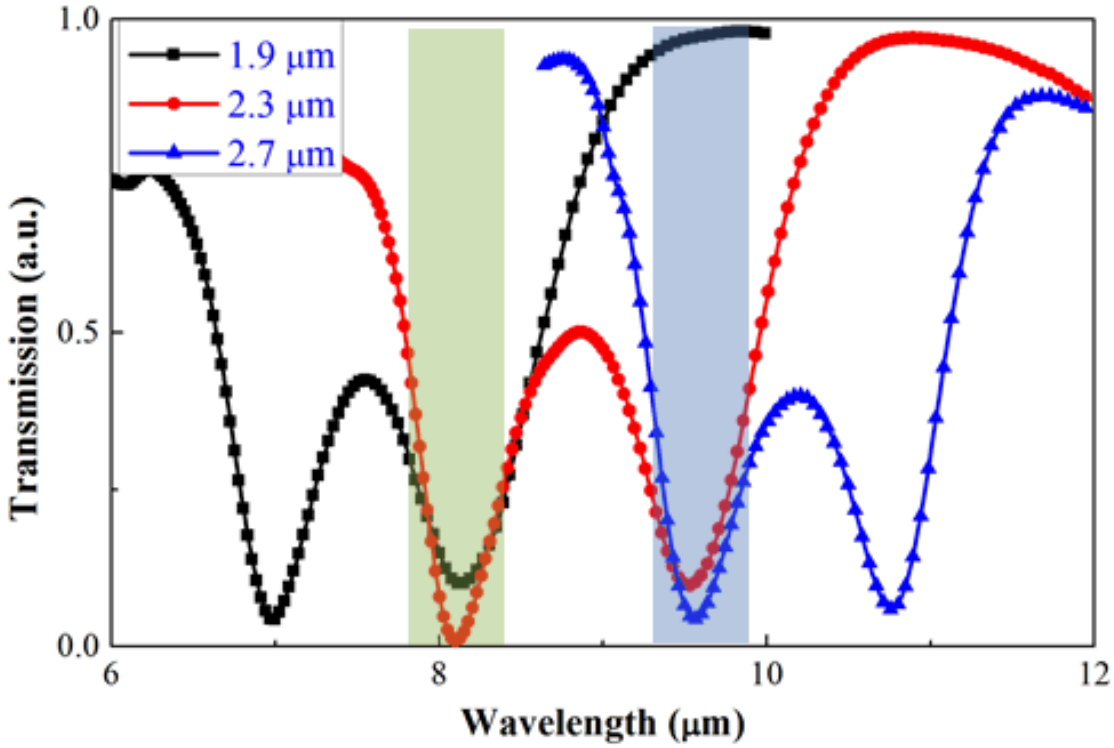
Height=1.45 μm **Height=1.2 μm** **Height=1.05 μm**



Side=1.45 μm **Side=1.6 μm** **Side=1.7 μm**

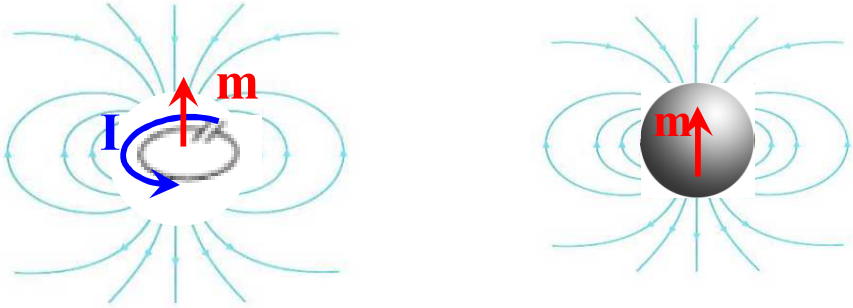
Transmission Spectra of Te metamaterial

- No polarizer is needed
- Tuning of electric and magnetic resonances
- Overlap of electric and magnetic resonances (potentially for achieving negative index material)



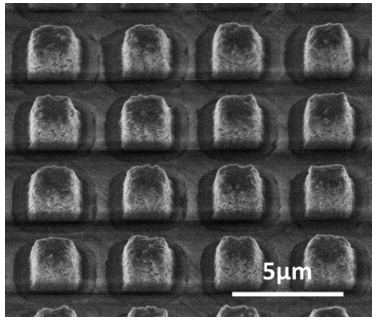
Summary

- Dielectric Mie resonator/metamaterial.

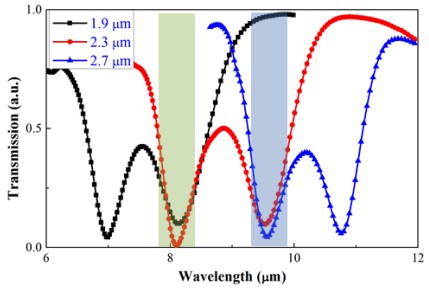


Thank you!

- Fabrication of Te cubic dielectric metamaterial
  - Undercutting and pinch-off issues
  - Multi-cycle of deposition-etching technique
  - Non-cubic shape resonators



- Transmission spectra and potential applications



Appl. Phys. Lett. **102**, 161905 (2013); http://dx.doi.org/10.1063/1.4803019