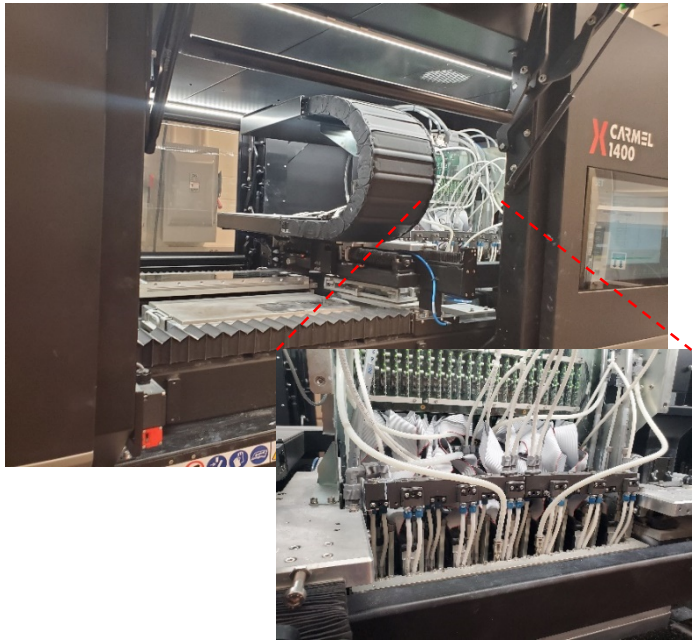
Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Ceramic Printing using NanoParticle Jetting™

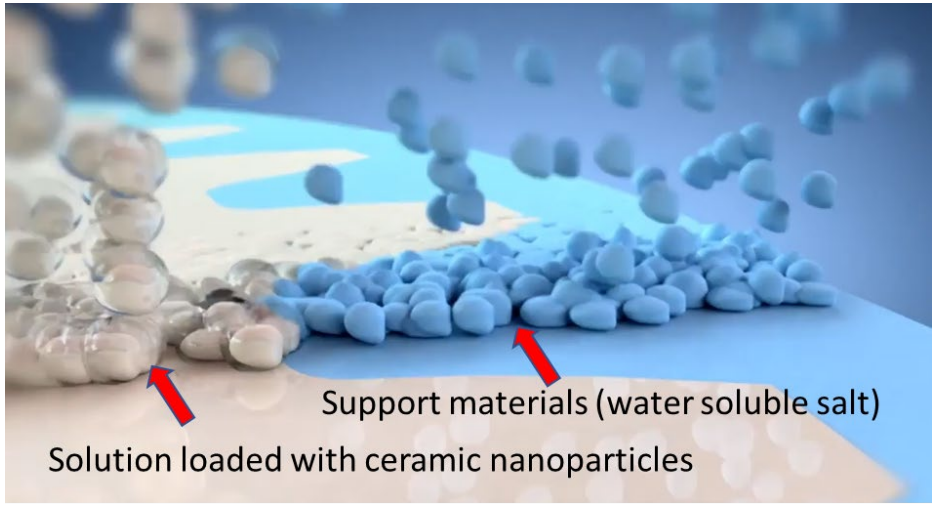
Maximum built size
(500 mm x 280 mm x 25 mm)

future z-height to 100 mm



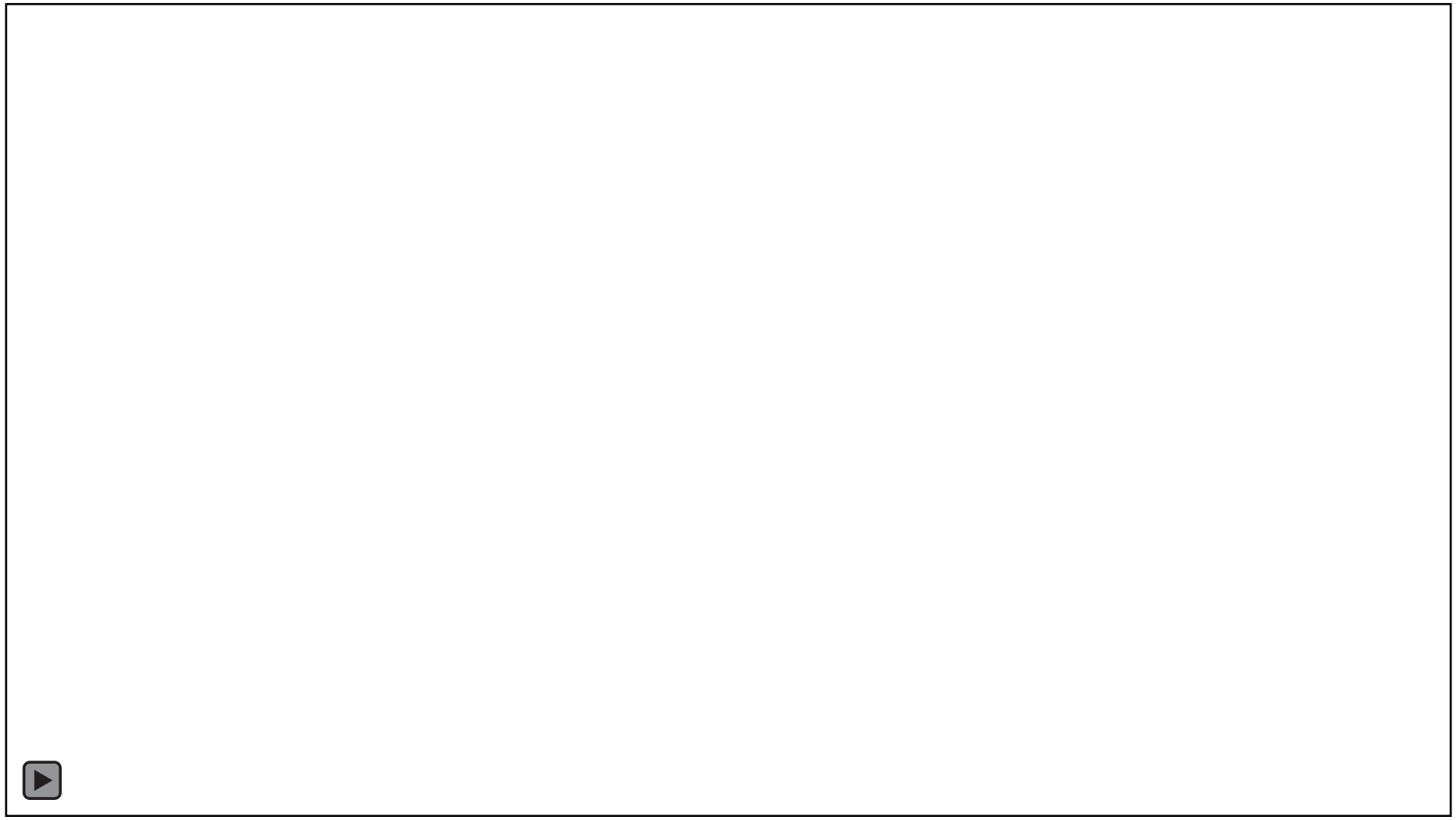
24 print heads, each containing 512 nozzles

Material jetting technology



- ❑ Layer height 10 μm
- ❑ Feature resolution 100 μm
- ❑ Currently works with zirconia (soon with alumina and 316 stainless steel)

Ceramic Printing using NanoParticle Jetting™



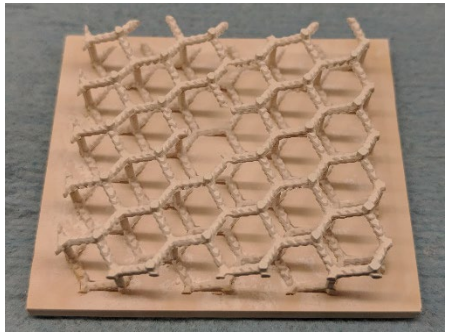
Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Ceramic Printing using NanoParticle Jetting™

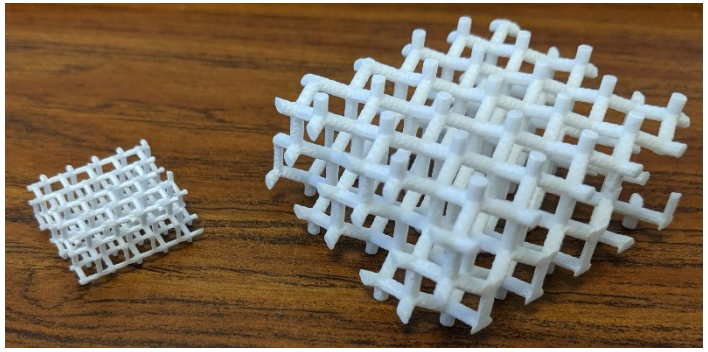
24 Print Heads
- 512 print nozzles per head
- 12,288 print nozzles total

1) Printing

2) Support Removal



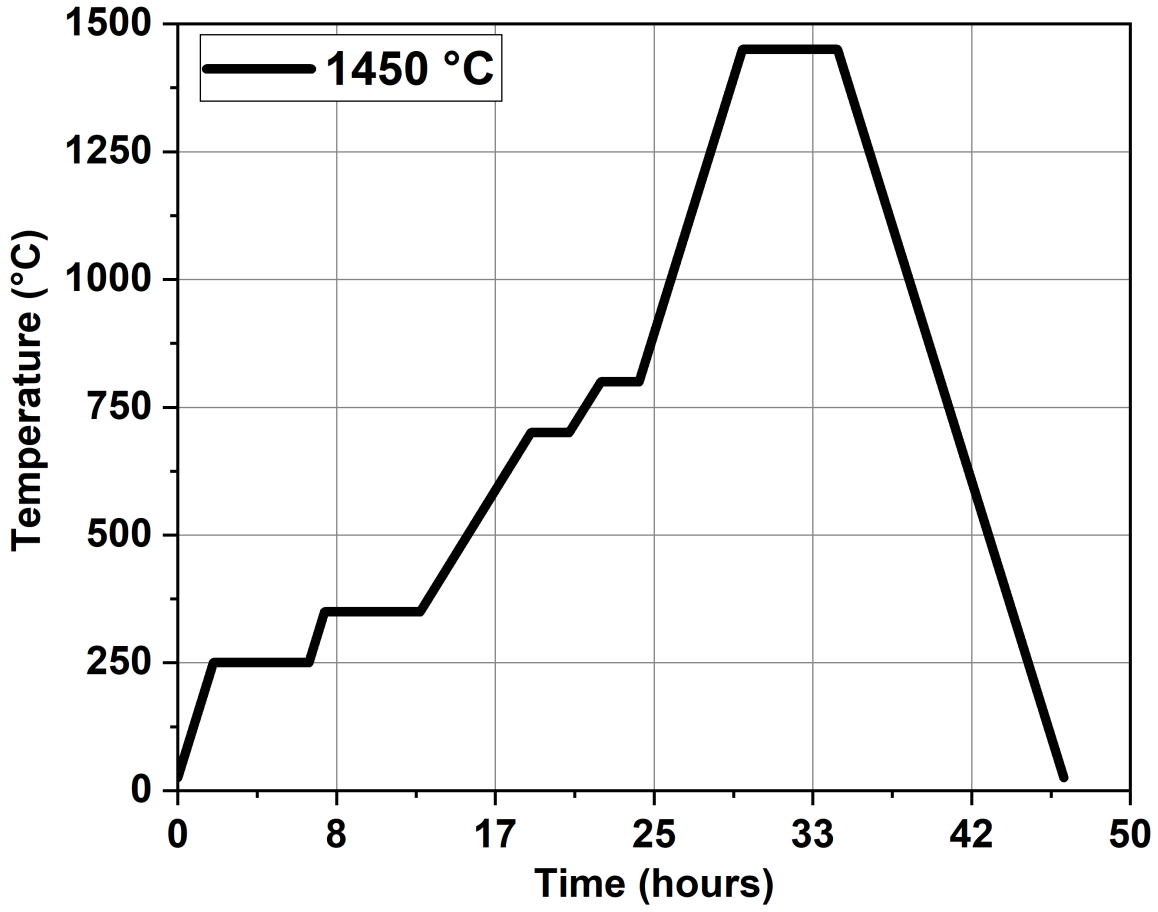
3) Drying

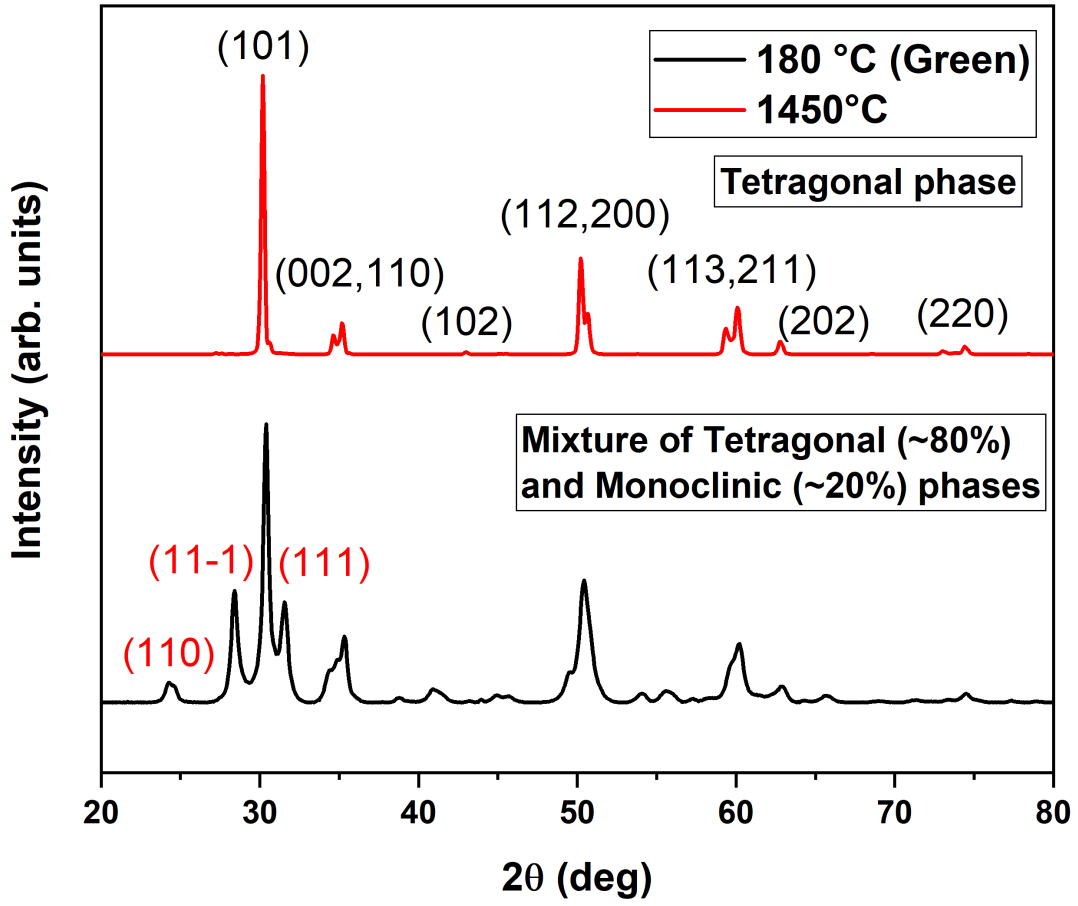


4) Sintering

Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Ceramic Printing using NanoParticle Jetting™





Ceramic Printing using NanoParticle Jetting™

Electromagnetic Material Properties of Printed Ceramic

$$\varepsilon_r^* = \varepsilon_r' - j\varepsilon_r''$$

Dielectric constant — Loss term

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'}$$

Loss tangent

These properties can vary considerably with frequency

	ε′	tanδ
Polyethylene	2.3	0.0002 @10GHz
Water	80	0.157 @3GHz
Alumina	10.0	0.0003 @10GHz
FR-4	4.2	0.008 @3GHz
ABS	3.0	0.019 @3GHz
Teflon	2.1	0.0003@3GHz

Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

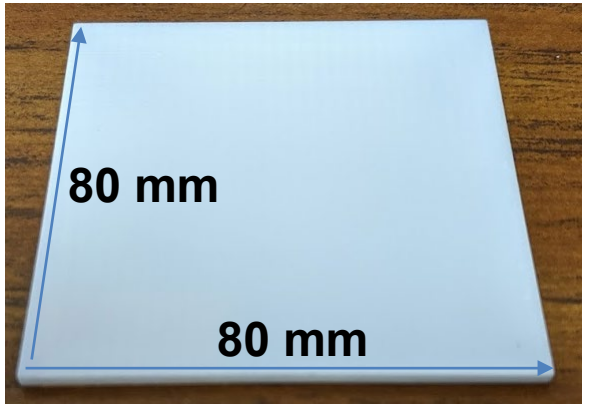
Ceramic Printing using NanoParticle Jetting™

Material EM Properties
(sintering temperature 1450°C)

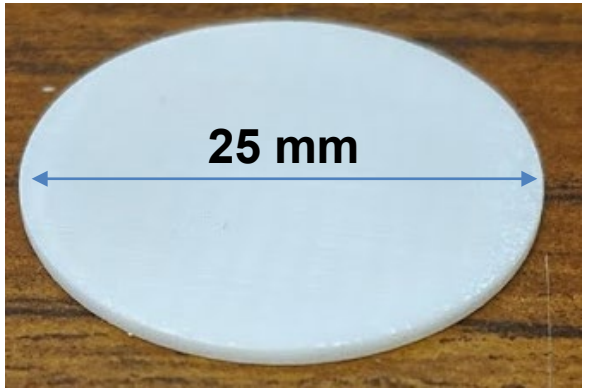
- Dielectric constant 31-32
- Loss Tangent < 0.005
- Isotropic volume reduction ~18%
- Density ~6.1 g·cm^{-3} (~99.9 % bulk density)

Measurements

- K-Ka band – NSWC Carderock
- W band - University of Delaware
- mm band – NJIT
- µm band – W.L. Gore (not included)



K-Ka/W/µm band samples



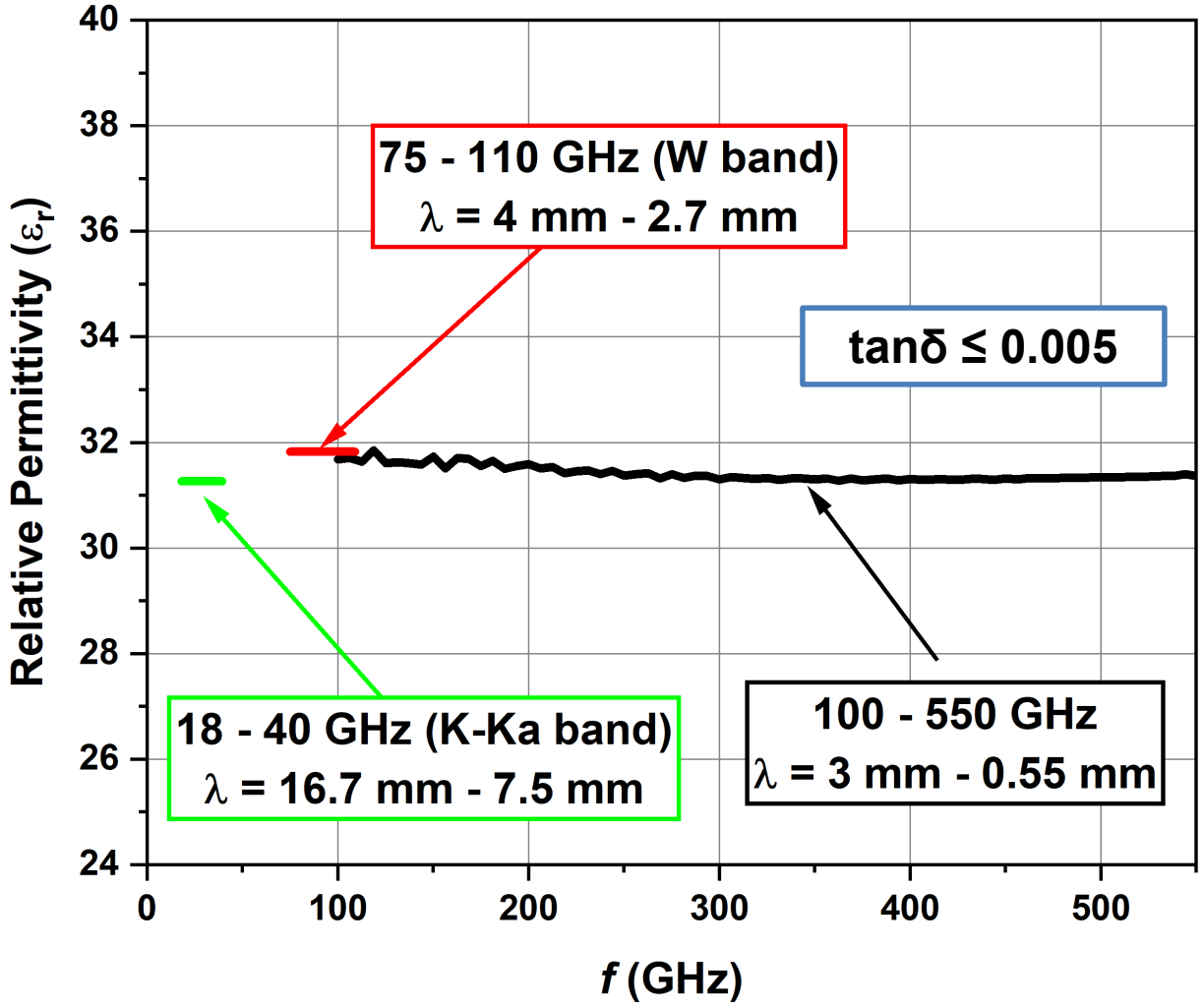
mm band samples

Additive Manufacturing of RF Devices and Systems

Ceramic Printing using NanoParticle Jetting™

Material EM Properties
(sintering temperature 1450°C)

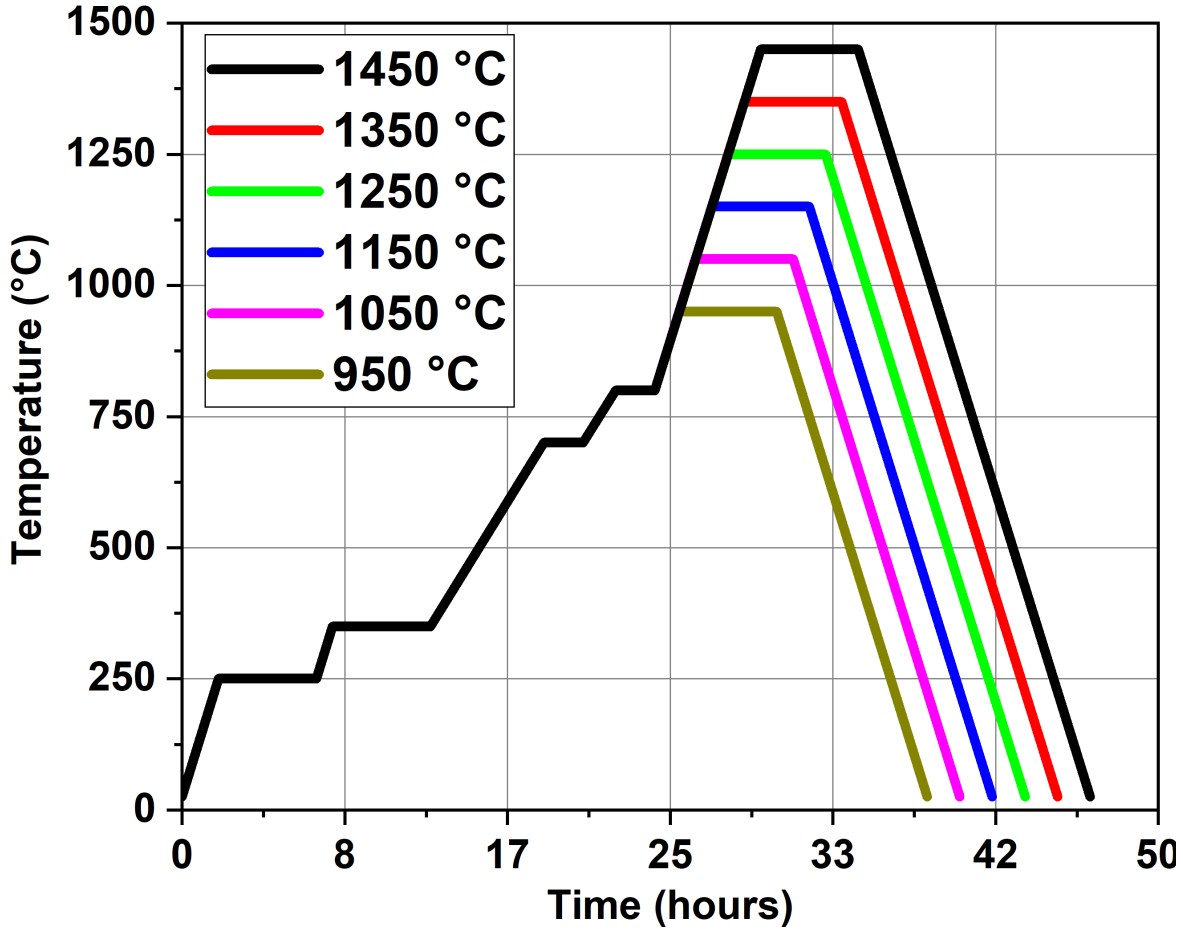
- Dielectric constant 31-32
- Loss Tangent < 0.005
- Isotropic volume reduction ~18%
- Density ~6.1 g·cm^{-3} (~99.9 % bulk density)

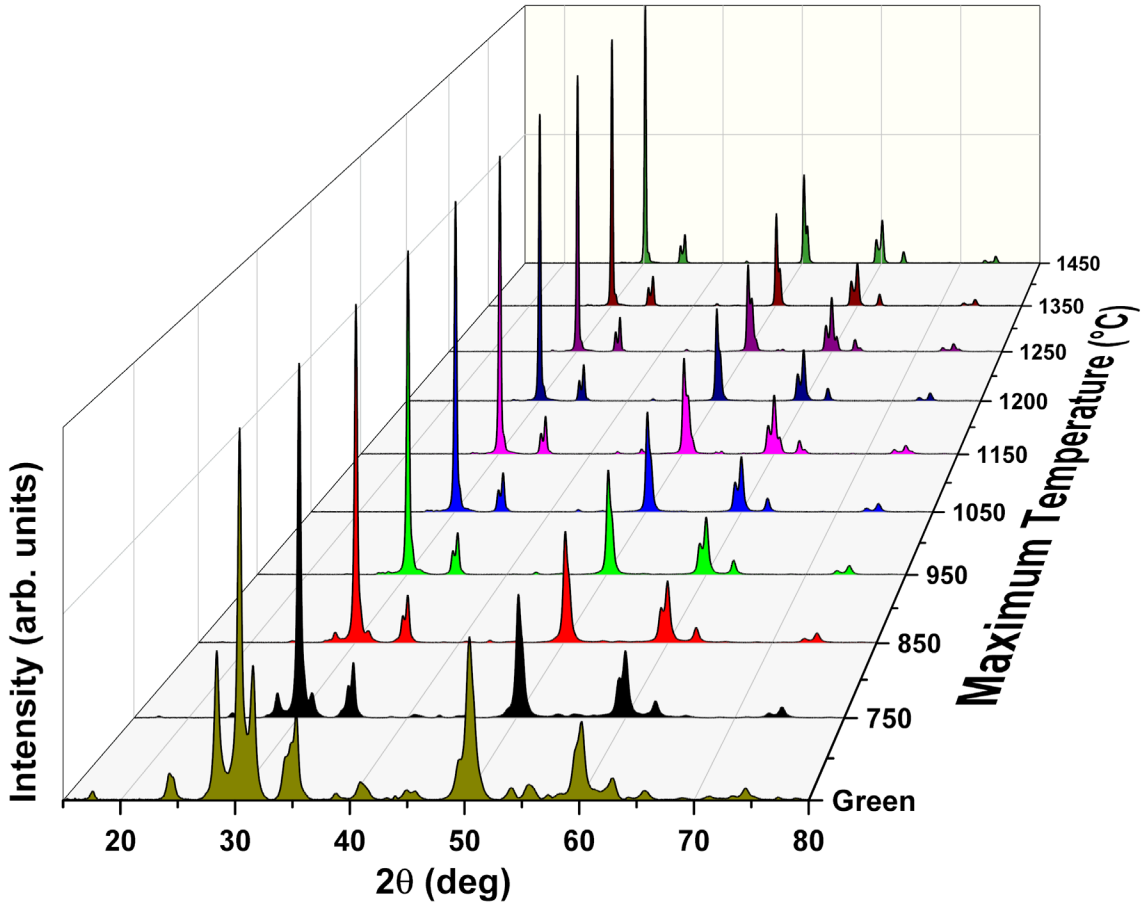


Additive Manufacturing of RF Devices and Systems

Ceramic Printing using NanoParticle Jetting™

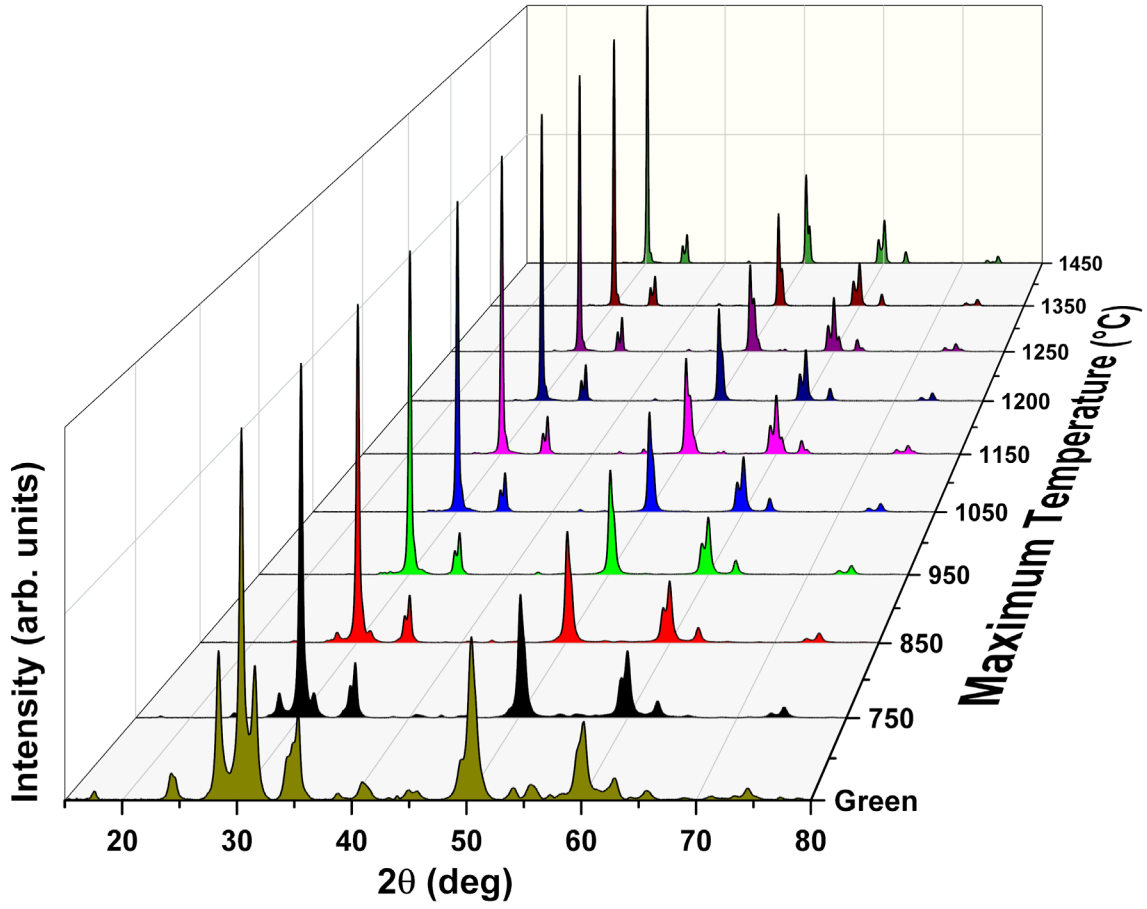
Explore the Effect of Sintering Profile on Electromagnetic Properties





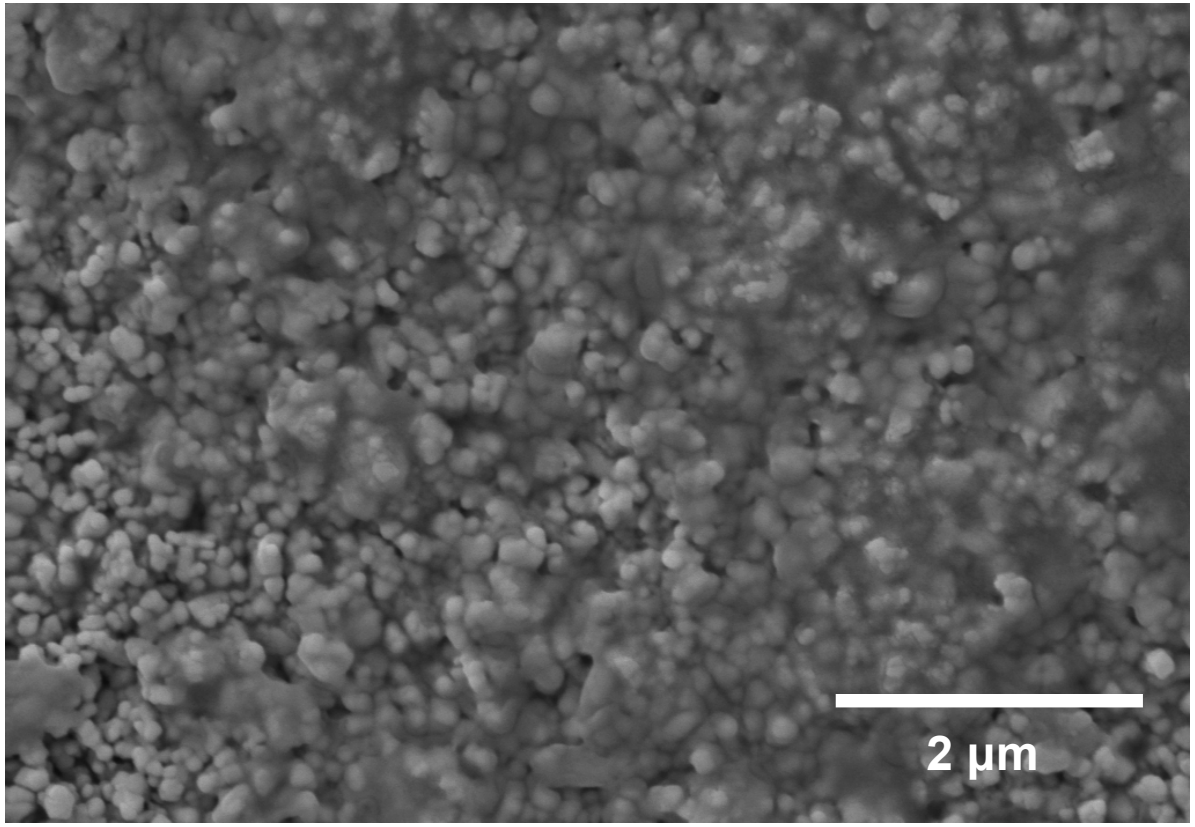
Ceramic Printing using NanoParticle Jetting™

Temperature (°C)	Scherrer Estimate (nm)
Green (180)	26.2
950	29.3
1050	31.4
1150	32.6
1250	34.4
1350	34.9
1450	36.7

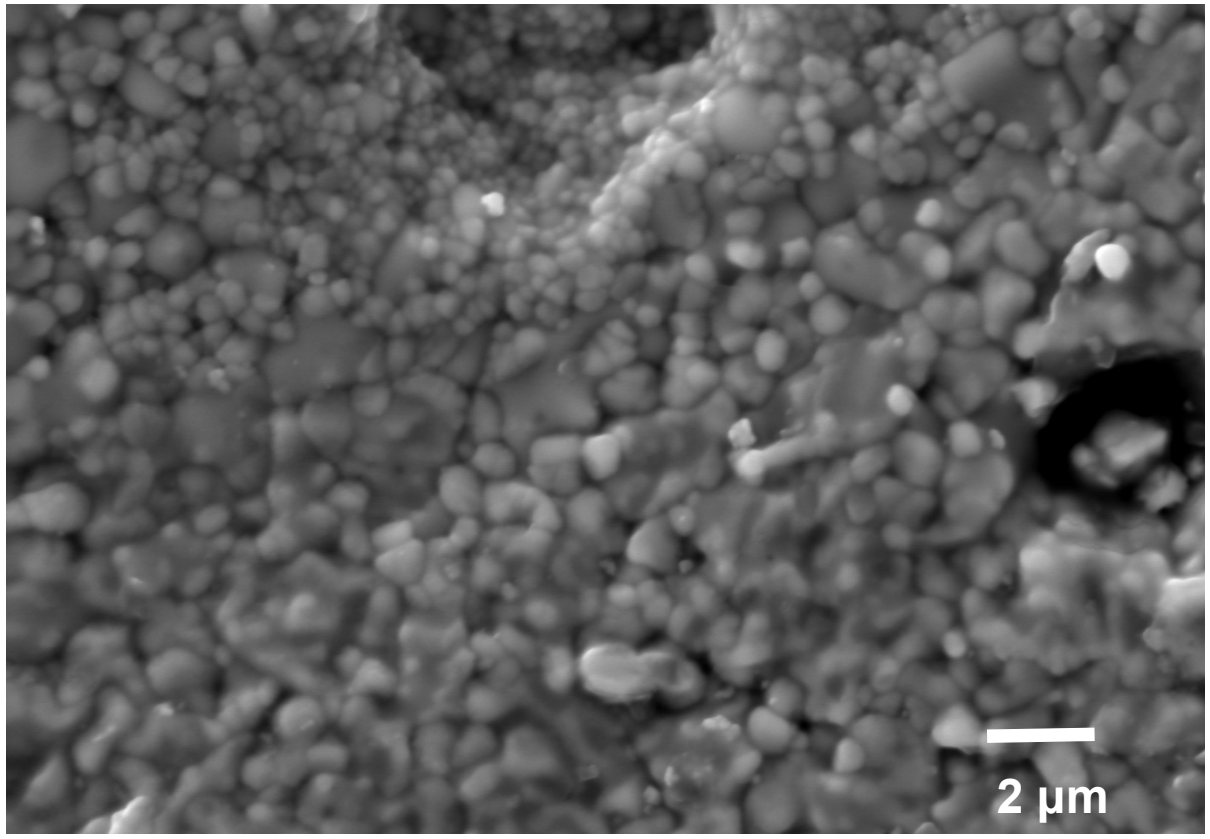


Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Ceramic Printing using NanoParticle Jetting™



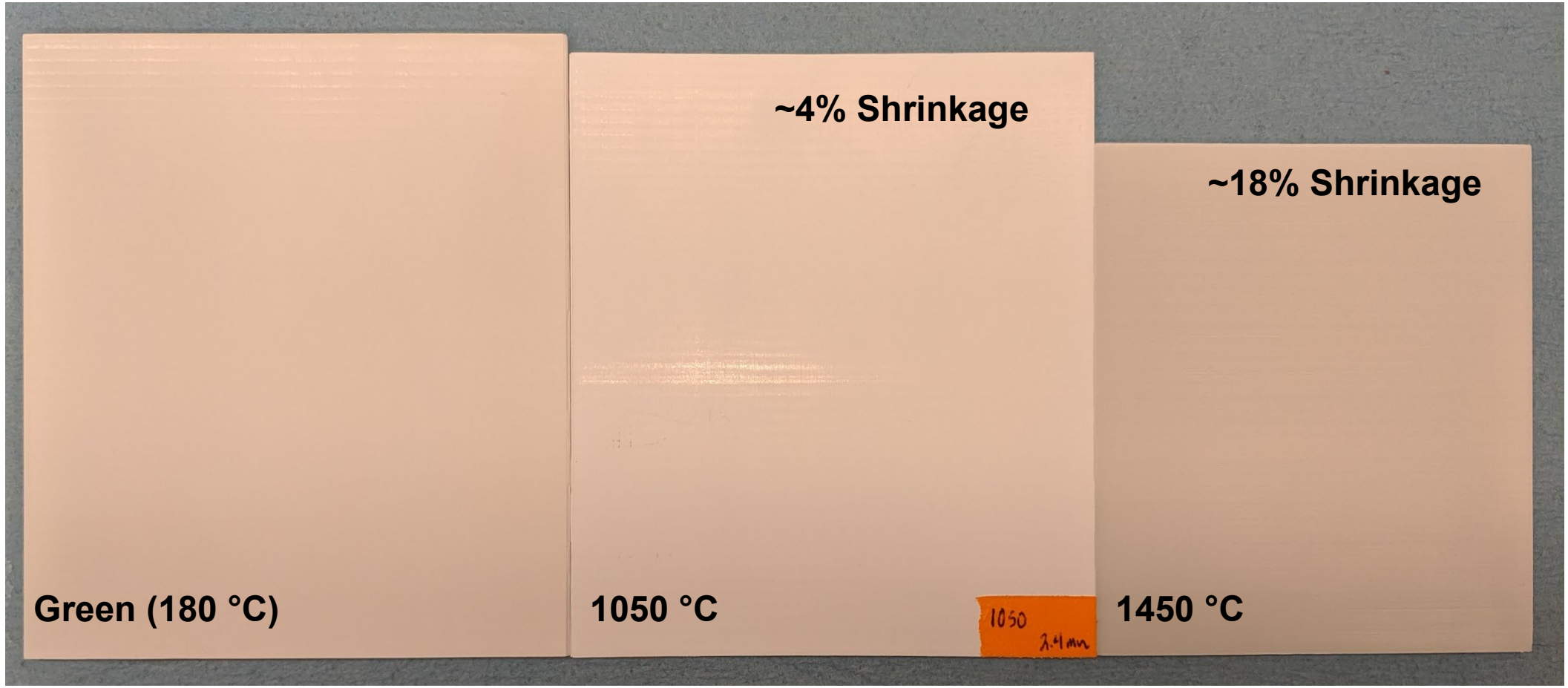
950 °C



1450 °C

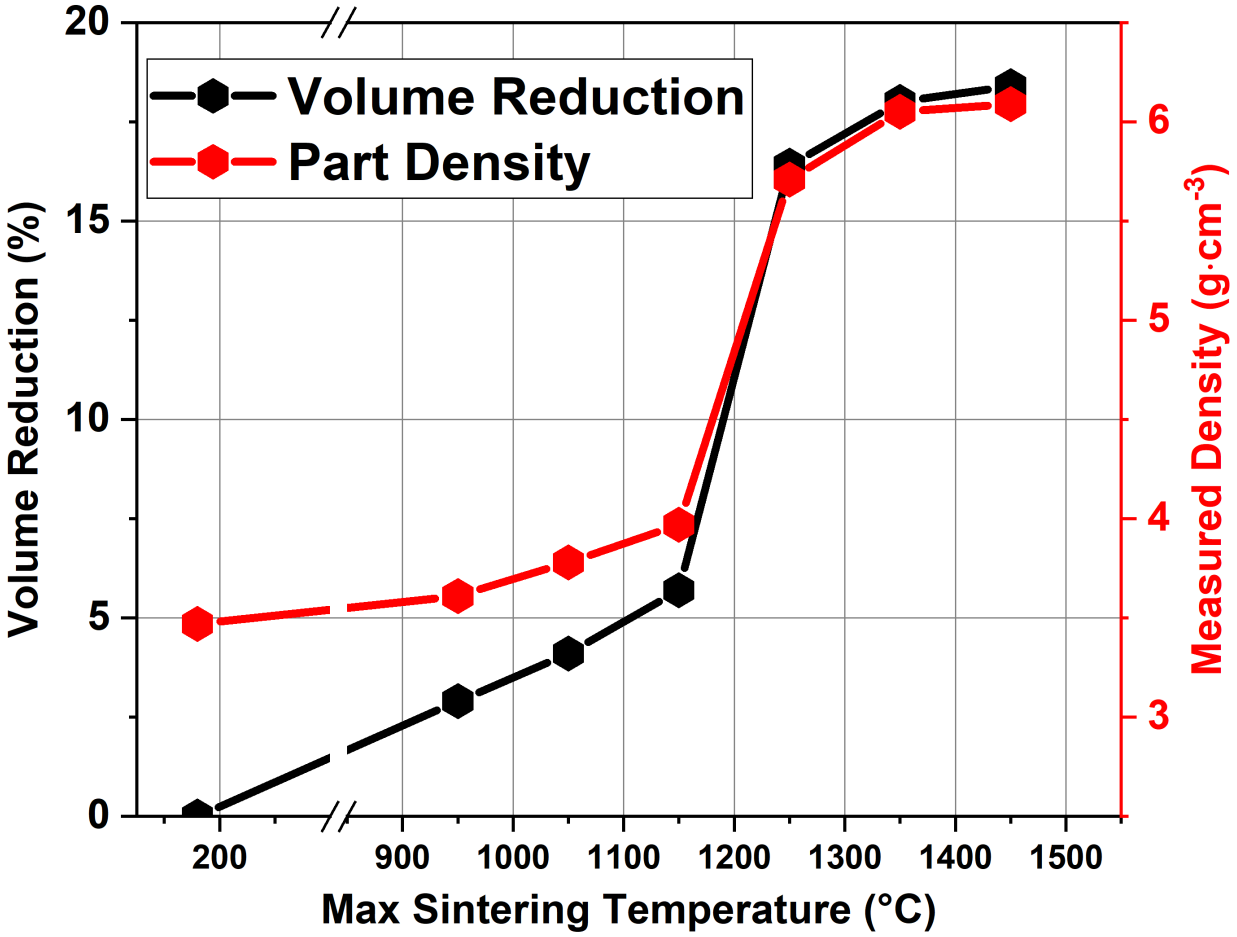
Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

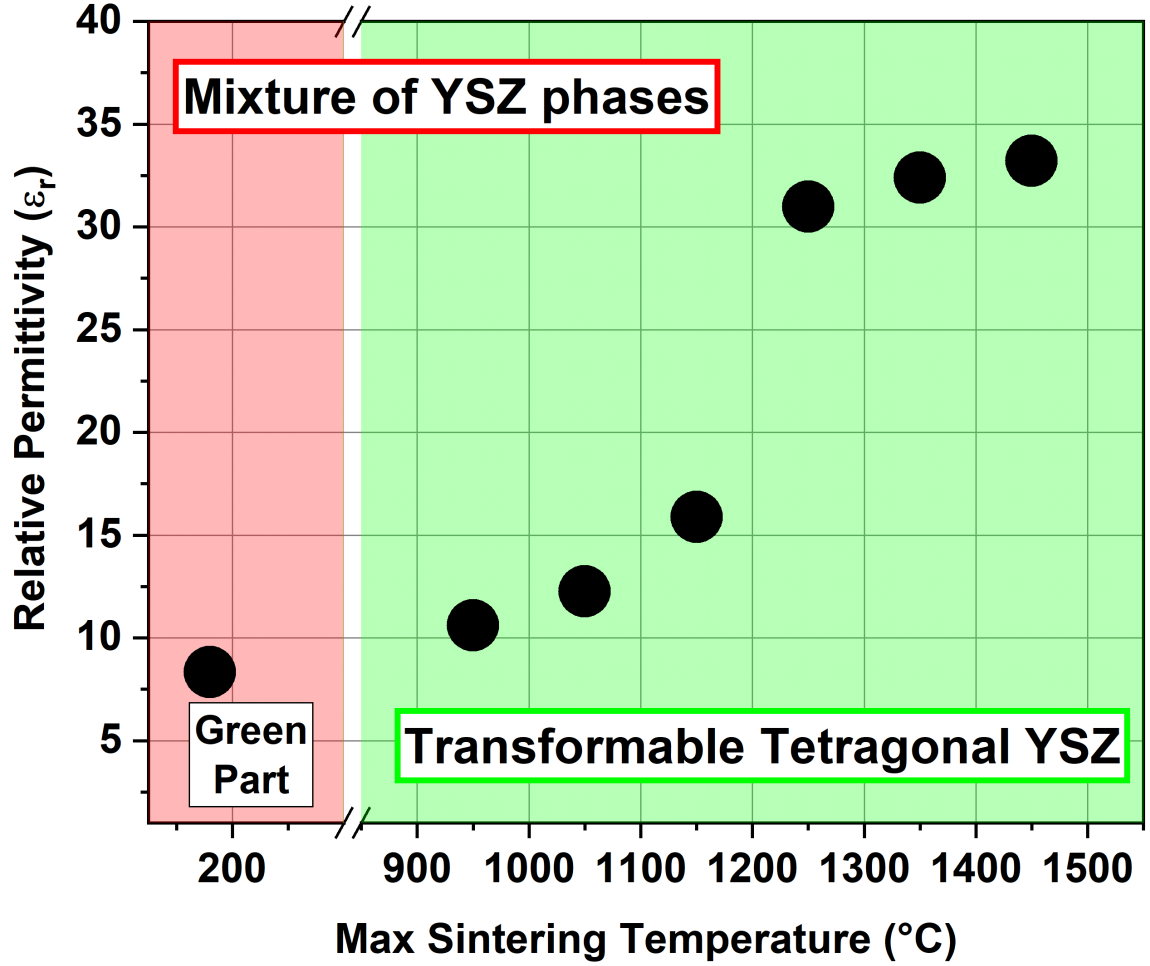
Ceramic Printing using NanoParticle Jetting™



Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Ceramic Printing using NanoParticle Jetting™





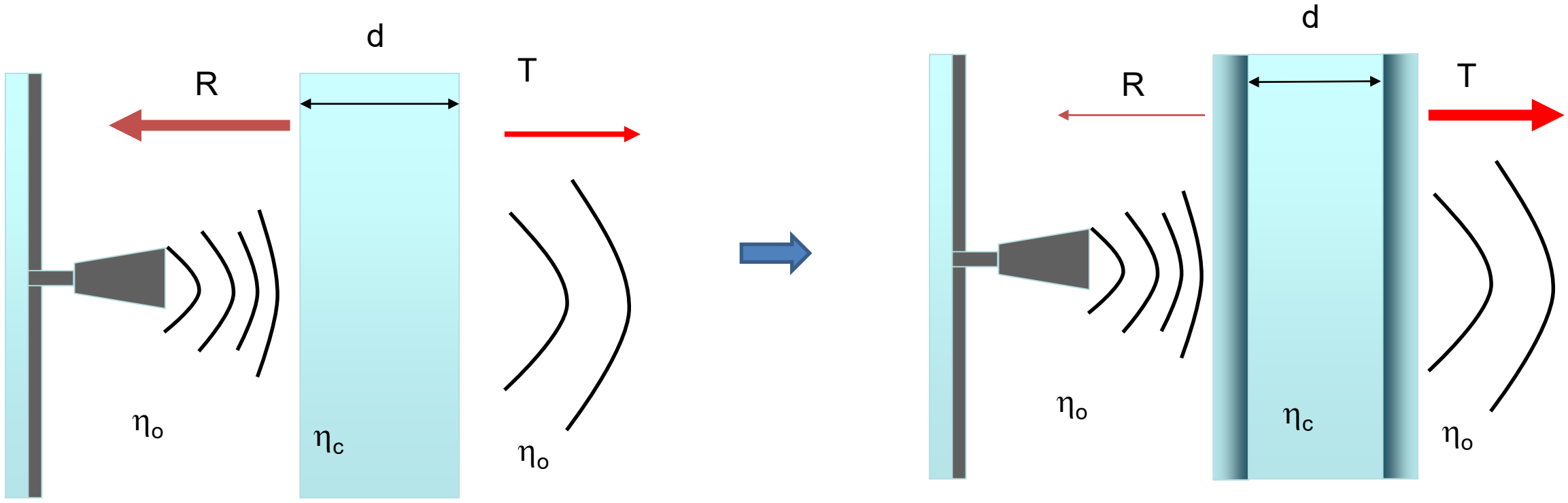
Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Application: High Temperature Radomes

- Radomes are needed to protect expensive antennas and electronics from both natural and operational conditions
- Radomes are designed to permit electromagnetic waves to be transmitted with little loss over a desired bandwidth.
- For very high temperature applications designing radomes can be quite challenging

Application: High Temperature Radomes

Ceramic radomes often have high reflective losses due to their high dielectric constant.



Application: High Temperature Radomes

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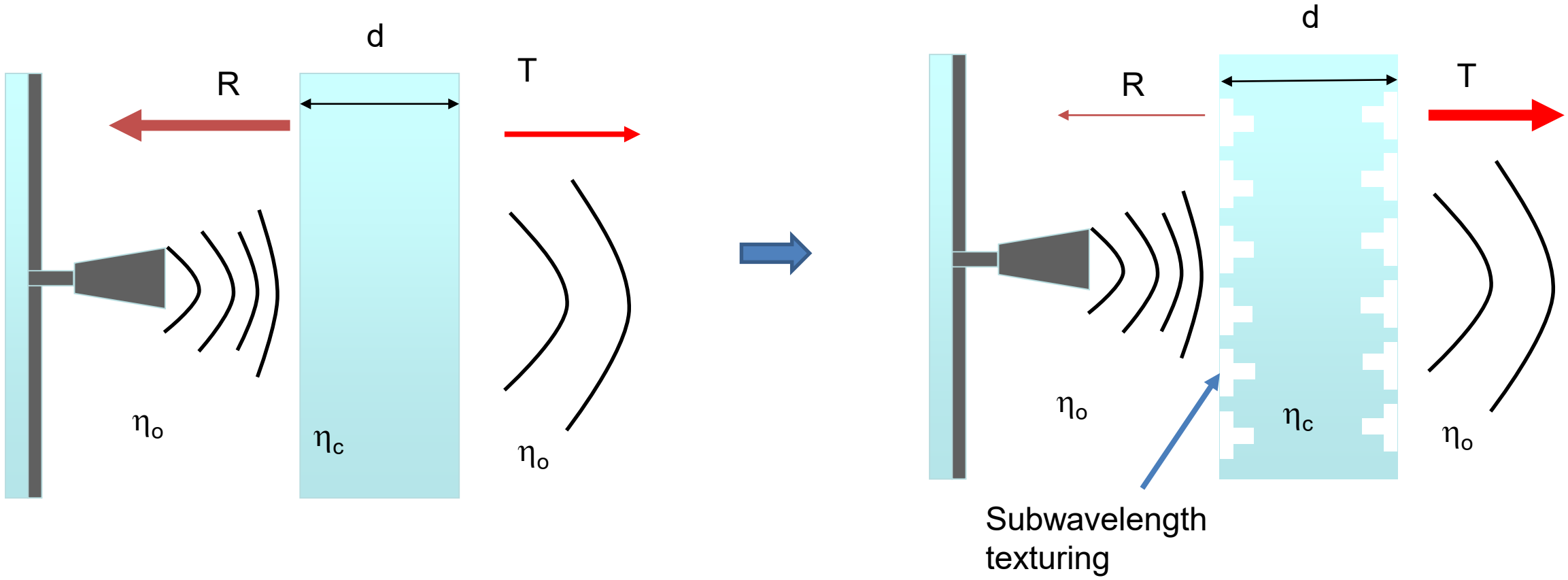
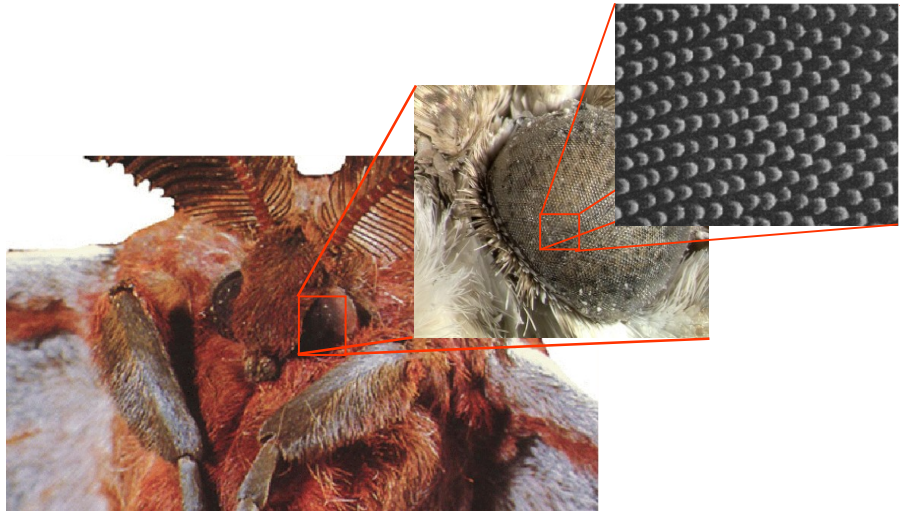


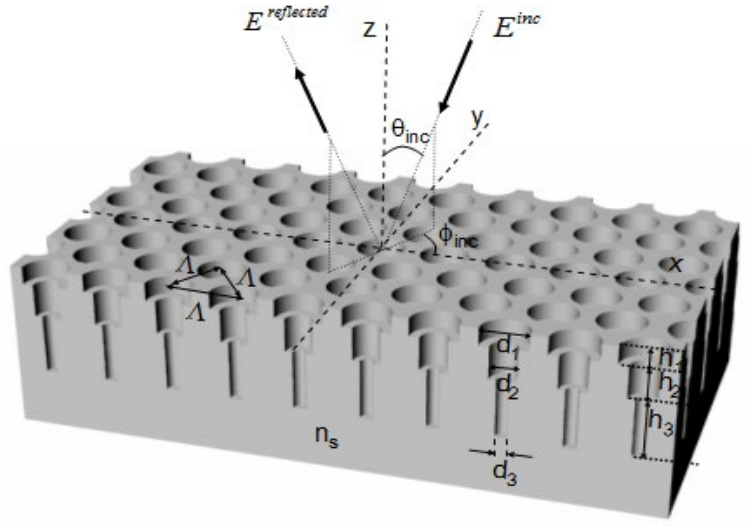
Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Application: High Temperature Radomes

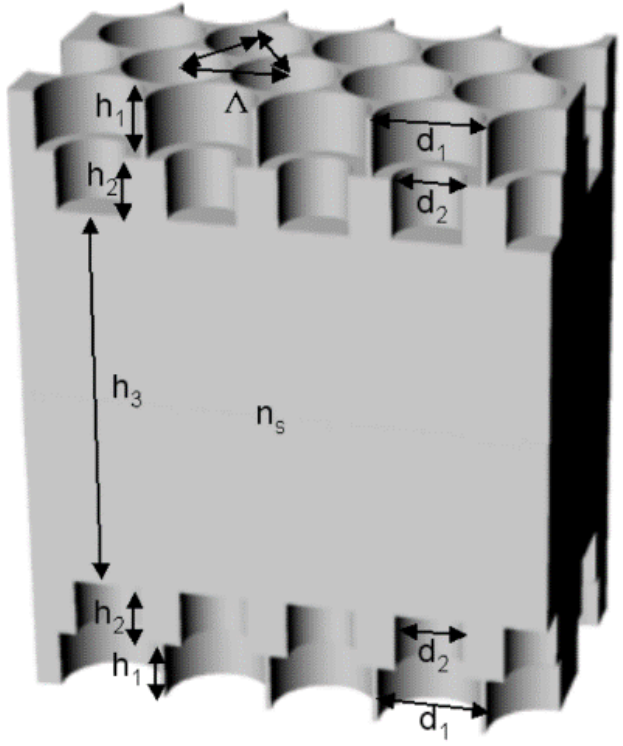
Motheye Antireflective (AR) Surface



Engineered AR Surface

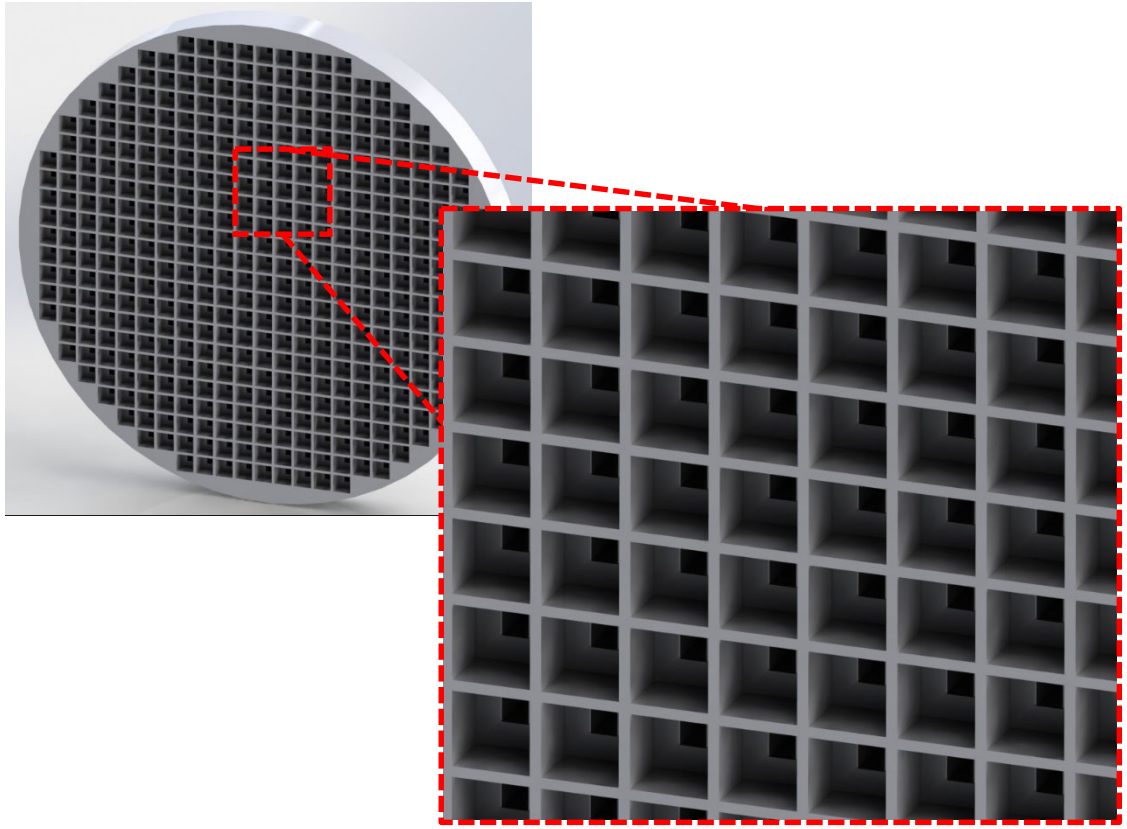


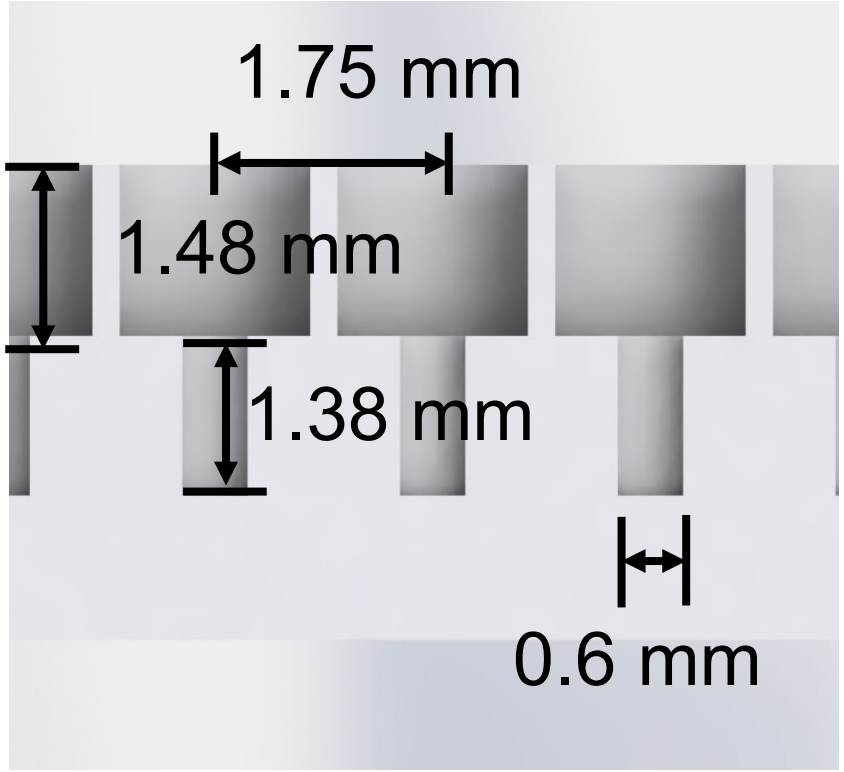
Radome



Application: High Temperature Radomes

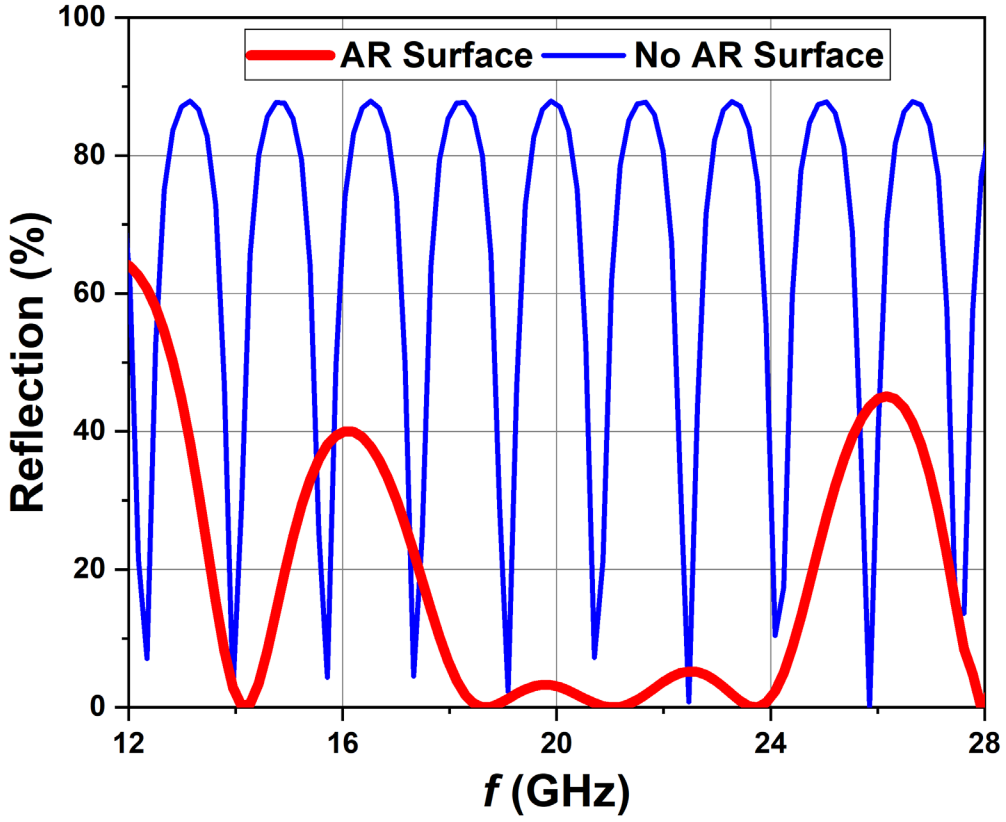
AR Surface (Textured Surfaces – Motheye Lens)

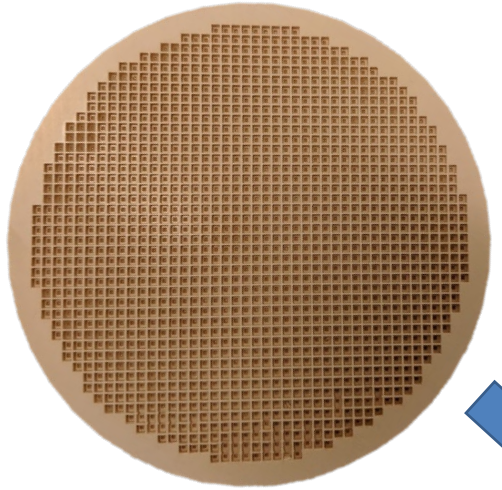


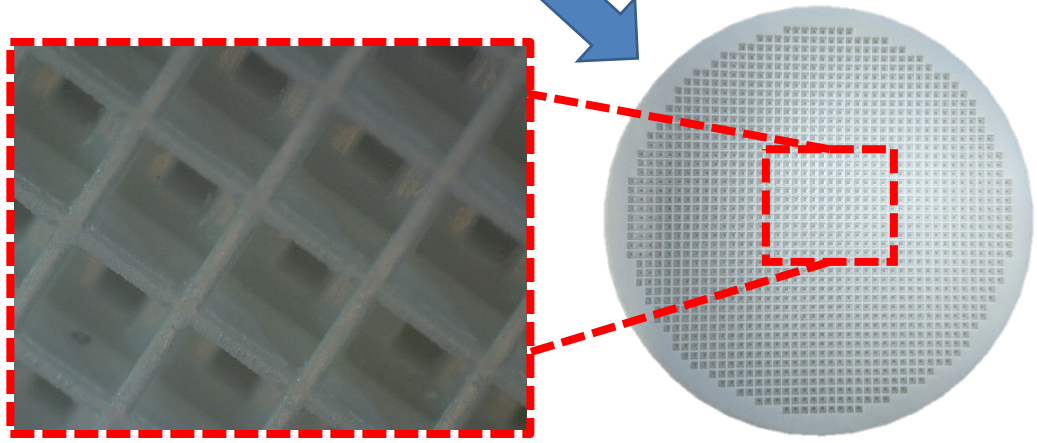


Application: High Temperature Radomes

AR Surface (Textured Surfaces – Motheye Lens)



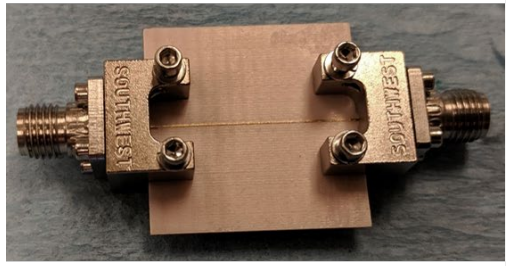


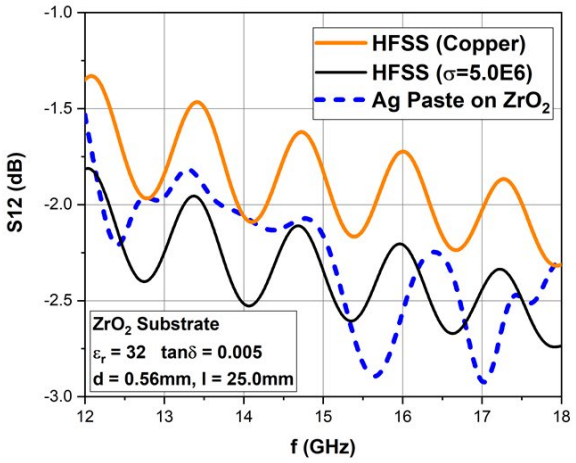


Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

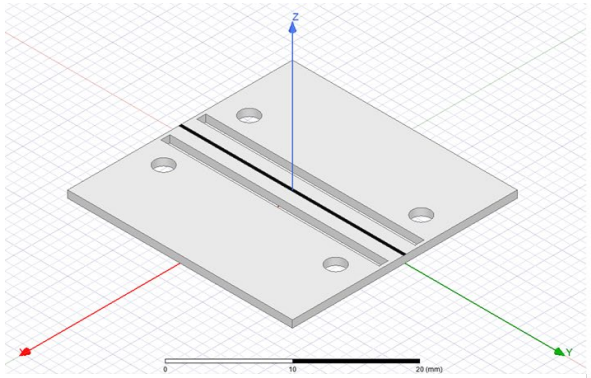
Application: Ceramic Substrates for Transmission Lines and Antennas

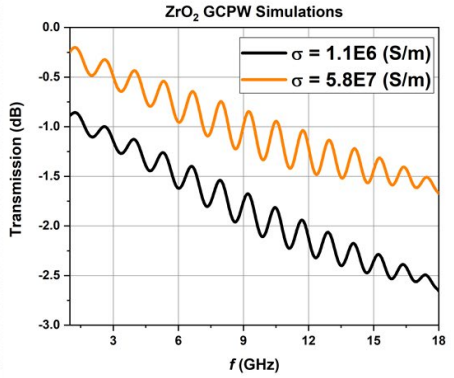
Transmission Lines





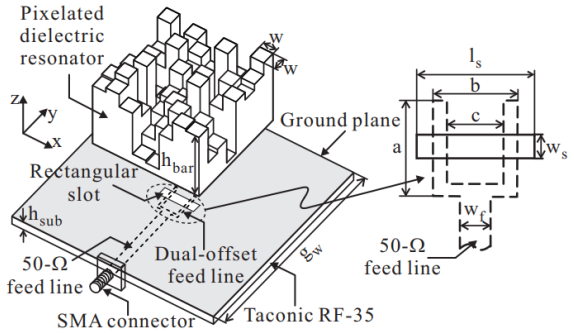
Microstrip transmission line





Grounded coplanar waveguide

Antennas



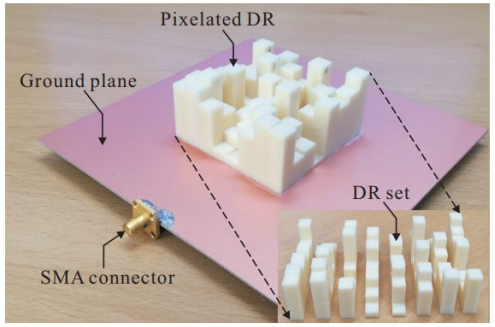


Figure 4. Photograph of the fabricated antenna.

sensors

MDPI

Article

A Wideband Circularly Polarized Pixelated Dielectric Resonator Antenna

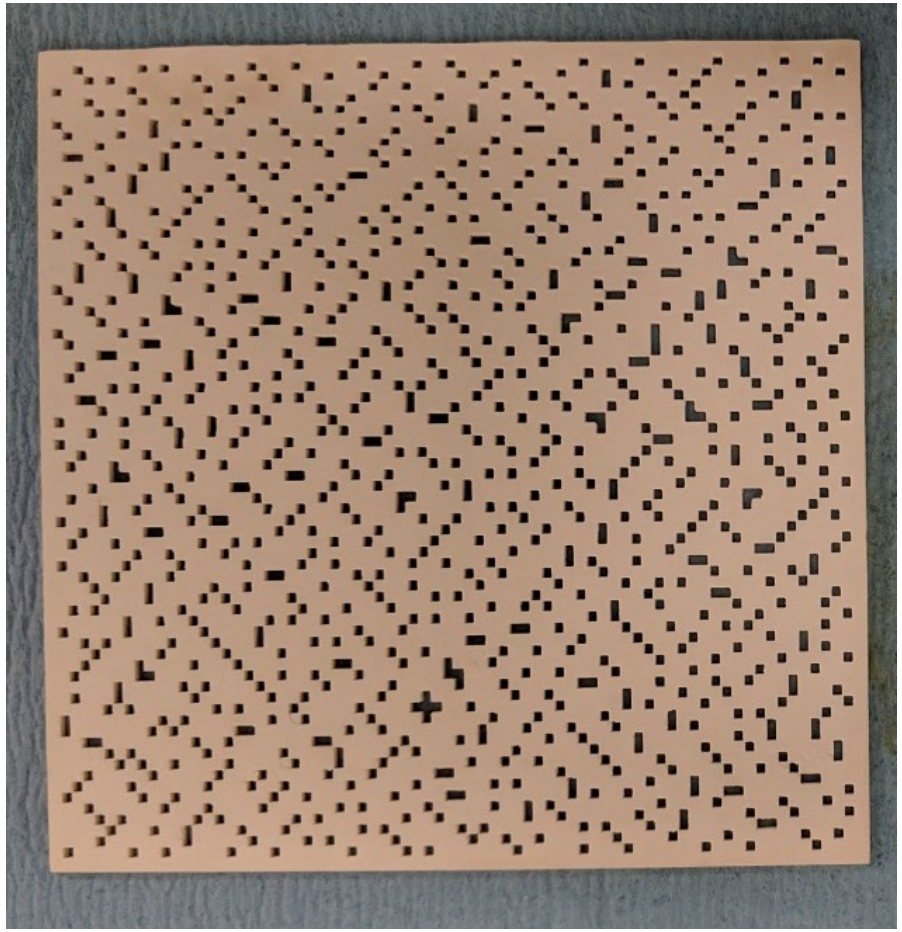
Son Trinh-Van, Youngoo Yang, Kang-Yoon Lee and Keum Cheol Hwang *

School of Electronic and Electrical Engineering, Sungkyunkwan University, Suwon 440-746, Korea; jsonbkhn@gmail.com (S.T.-V.); yang09@skku.edu (Y.Y.); klee@skku.edu (K.-Y.L.)
* Correspondence: khwang@skku.edu; Tel.: +82-31-290-7978

Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Application: Coded Apertures for X-ray Imaging

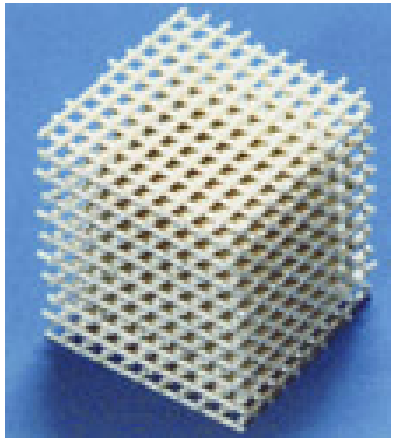
Zirconia Coded Aperture



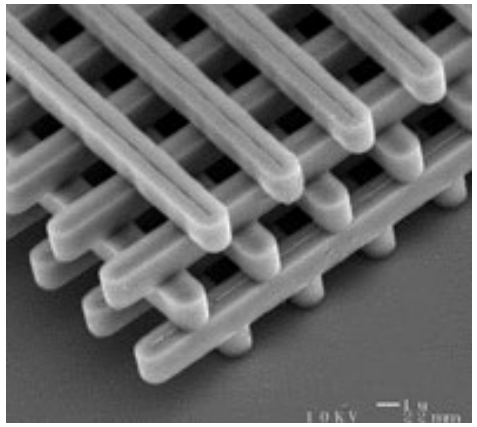
X-ray Transmission

Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

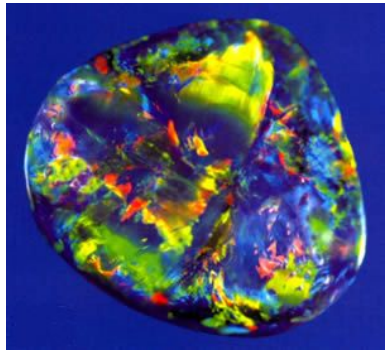
Application: Photonic Crystals



Iowa State University Ames Lab



Sandia National Laboratory



Natural photonic crystal (Opal)

Natural photonic crystal (butterflies)

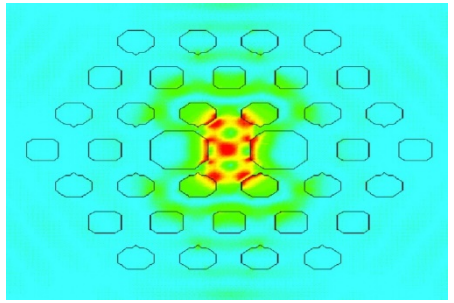
Photonic crystals: periodic dielectric structures.

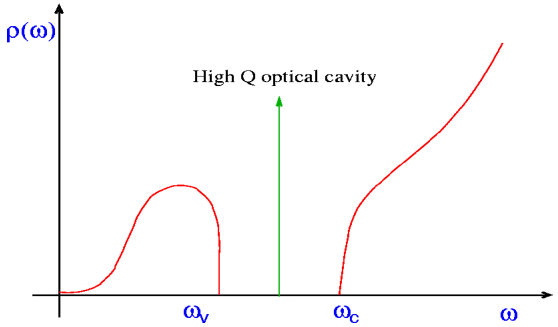
- interact resonantly with radiation with wavelengths comparable to the periodicity length of the dielectric lattice.
- properties vary with frequency
- may present complete band gaps in which electromagnetic waves will not propagate in any direction over a band of frequencies

Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

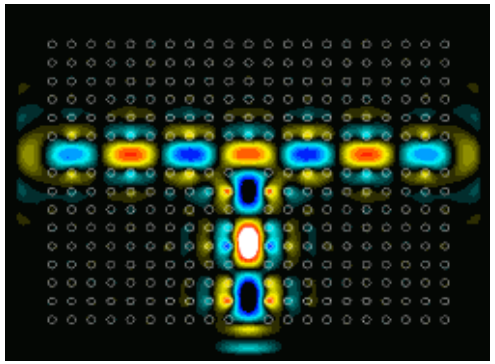
Application: Photonic Crystals

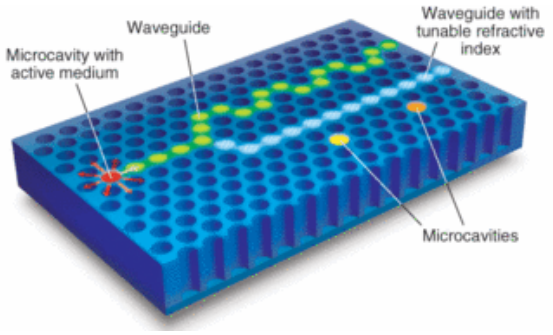
High Q Cavities



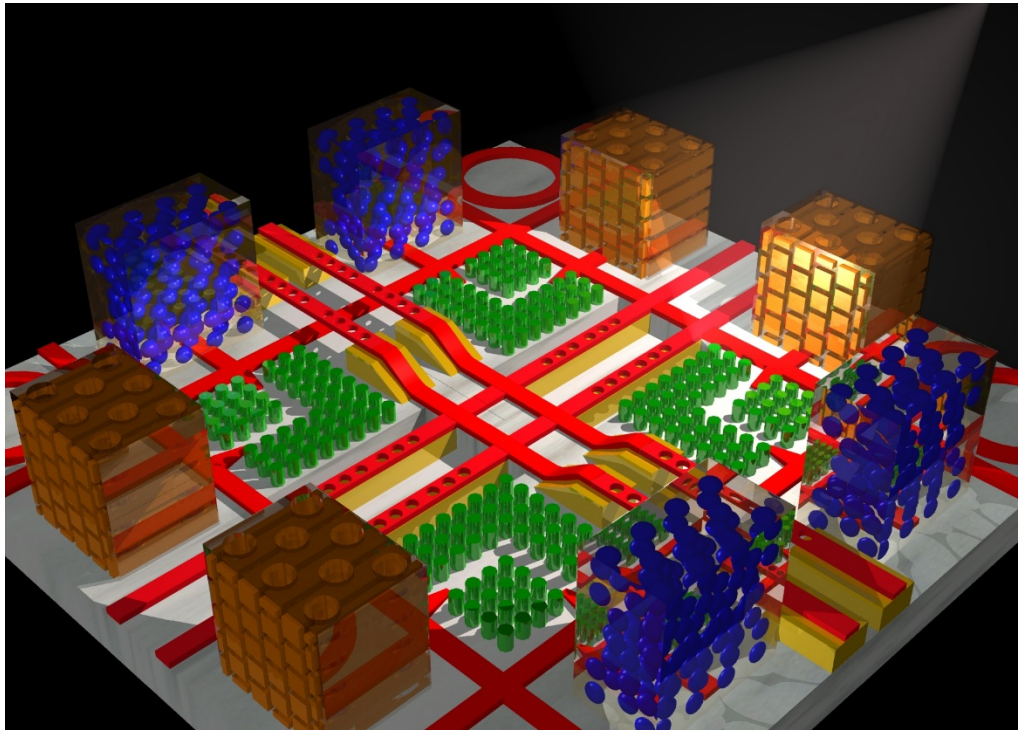


Waveguides





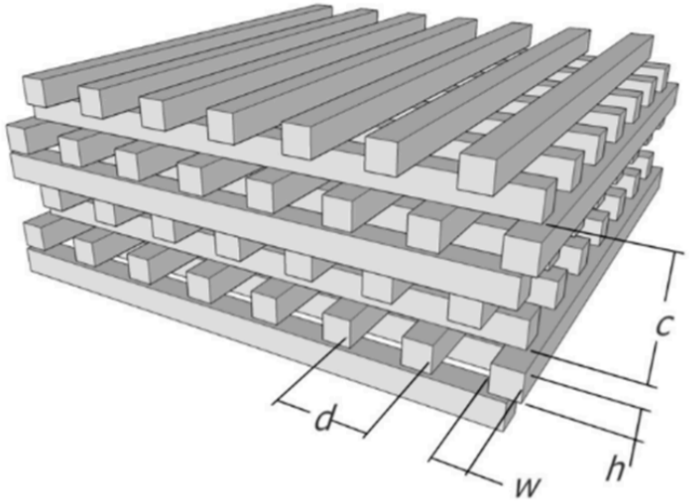
Integrated RF and Optical Systems



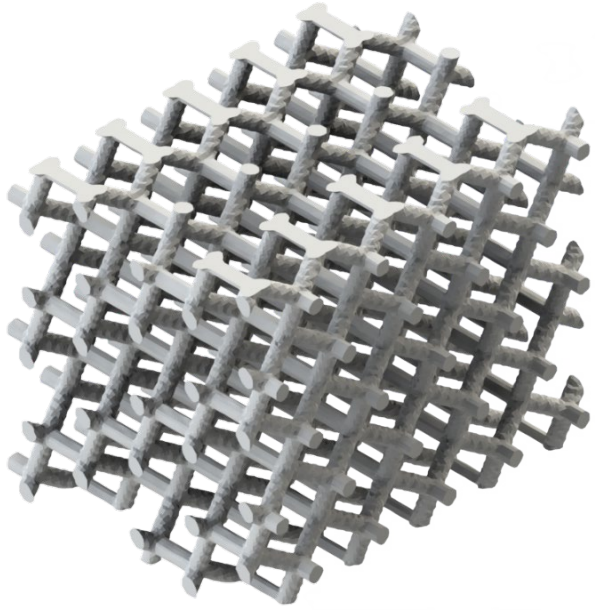
STEVEN G. JOHNSON, MIT

Application: Photonic Crystals

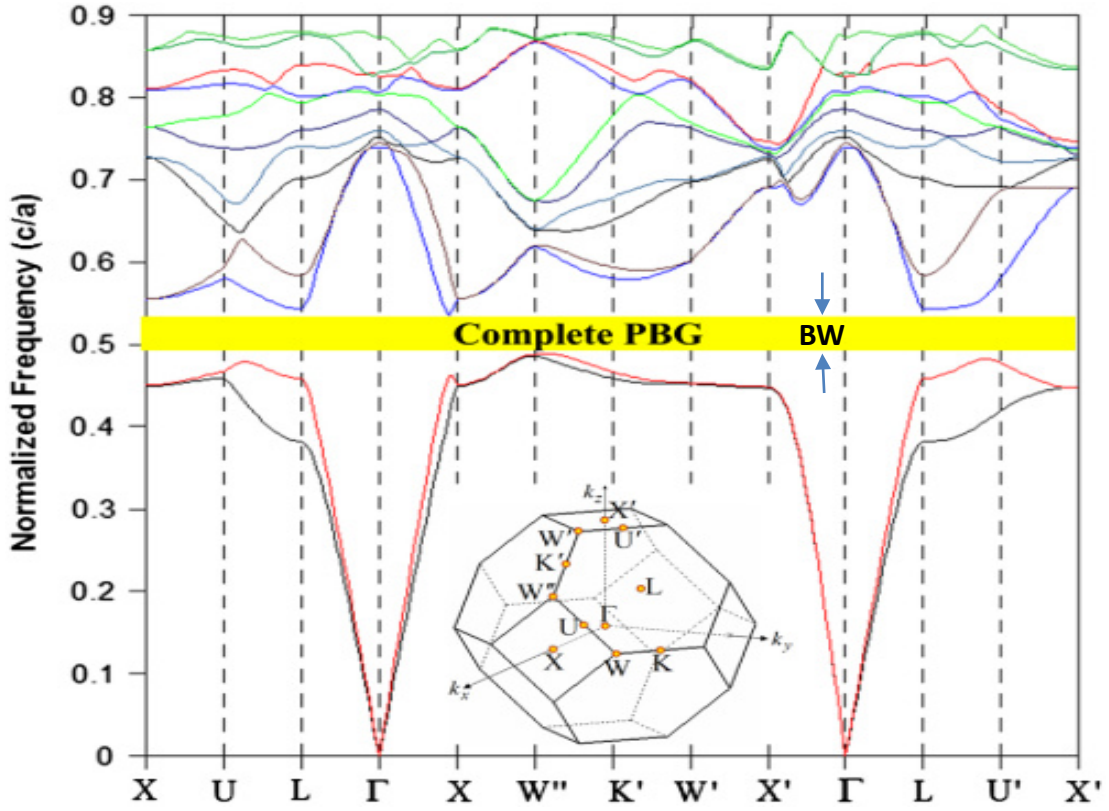
Full 3D Photonic Crystals



3D Logpile



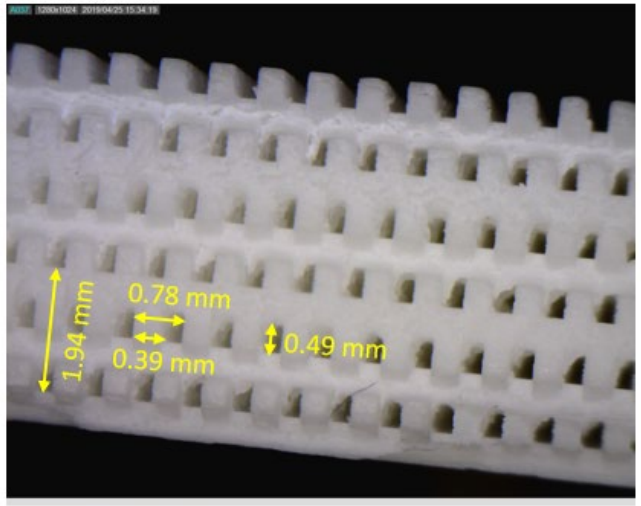
3D Diamond Lattice

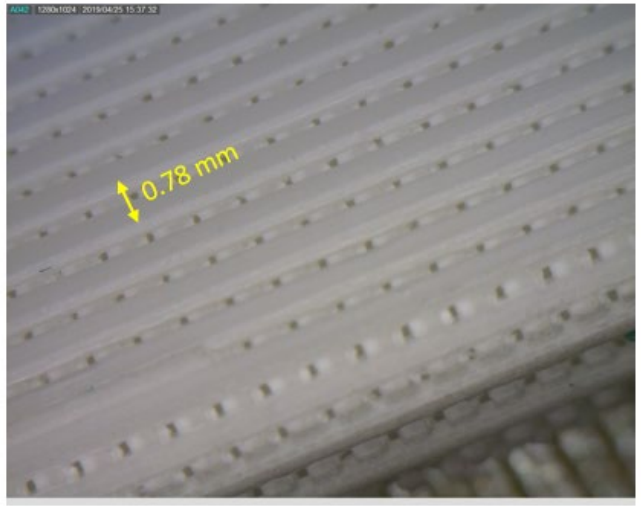


$$\%\text{Band gap} = 100 \times (BW / f_o)$$

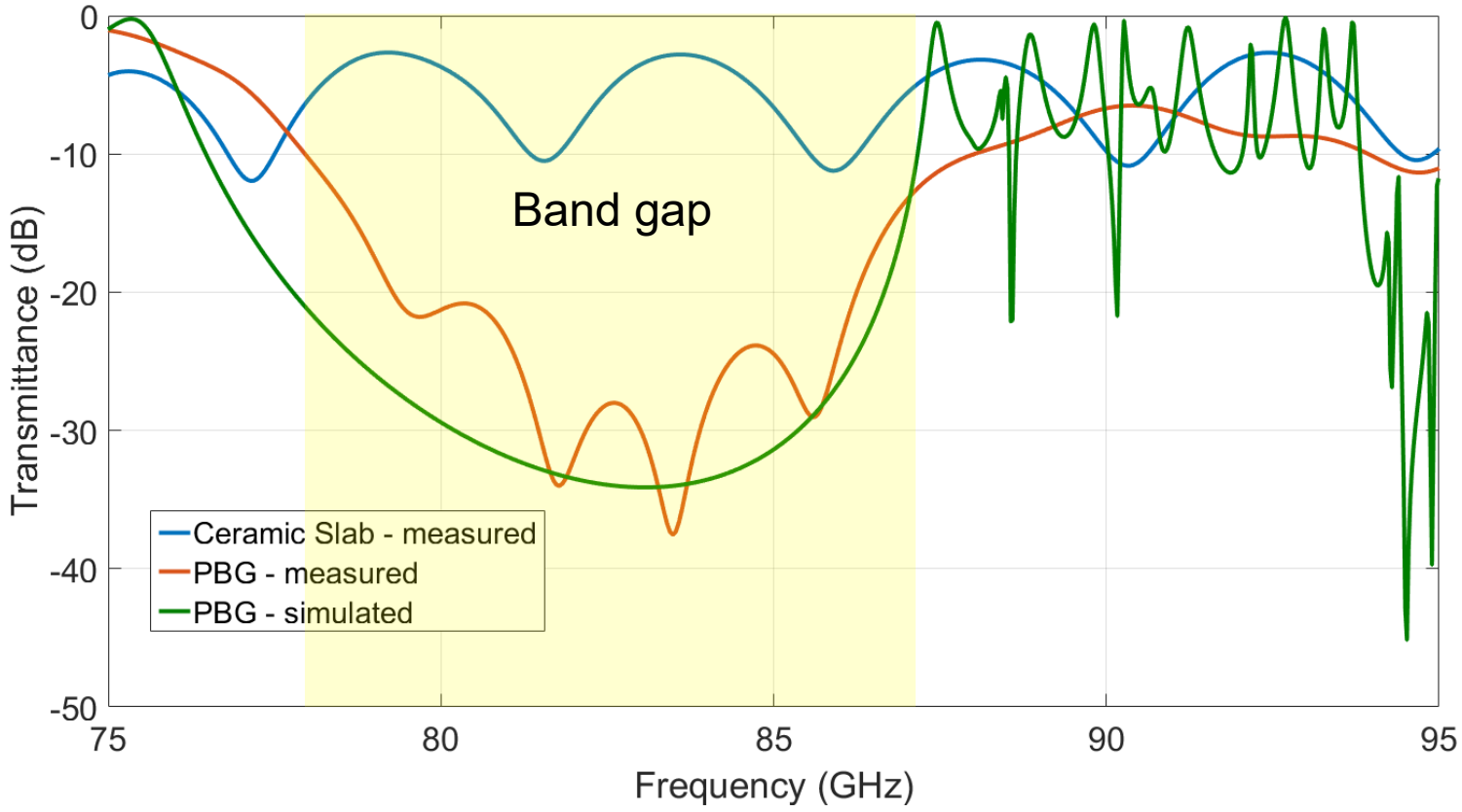
Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Application: Photonic Crystals





Full 3D Bandgap Logpile Design

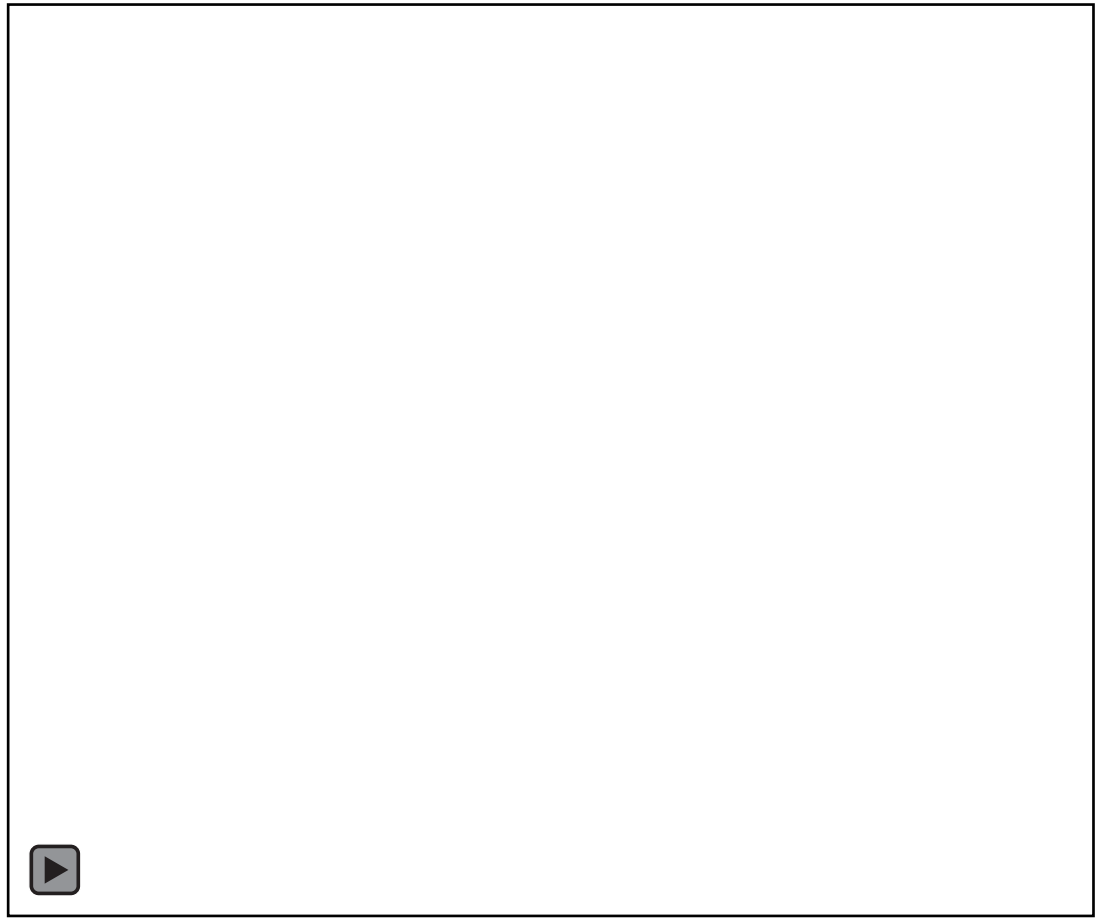


Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Application: Photonic Crystals

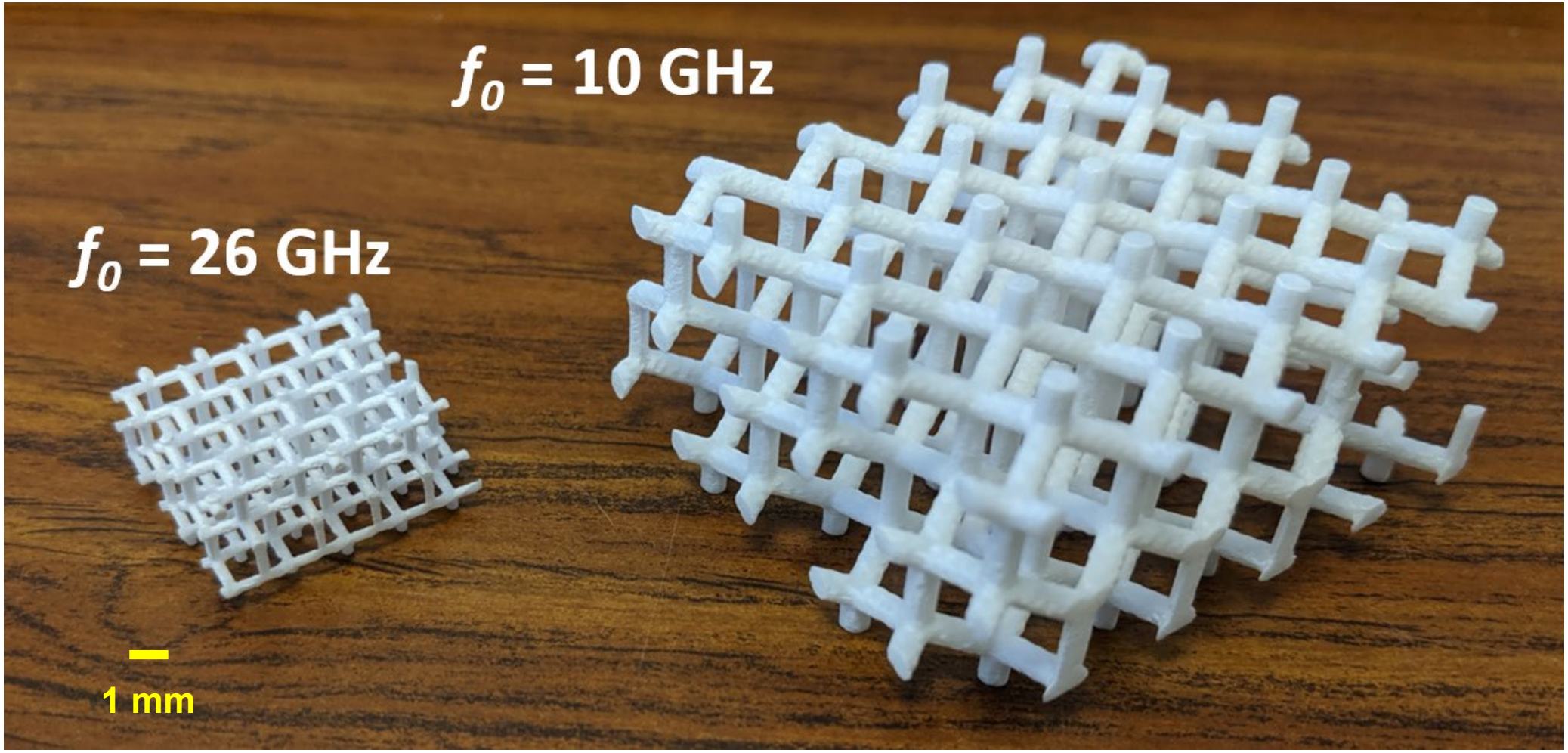
Collaboration with MIT
(S. Johnson and J. Joannopoulos)

- Proposed a diamond lattice design
- Can theoretically achieve a complete band gap of 52%
  - Current record is 30%(Nature Materials, 3, 593-600,2004)
  - Possible only due to extremely high dielectric constant contrast
- Scalable to RF/microwave frequency range of interest



Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Application: Photonic Crystals



K-Ka and X band Crystal – Designed with center frequency, f_0, of 26 GHz and 10 GHz.

Additive Manufacturing of Ceramic Structures for Electromagnetic Applications

Application: Photonic Crystals

RF Photonic Crystals