Micro-printing of Metallized Ceramics for Microelectronics

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Panel: Creating Value with Ceramics Additive Manufacturing

Ceramics Expo

May 2- 3, 2023, Novi MI

HRL Laboratories

Limited Liability Company (LLC) Located in Malibu, Calabasas, and Camarillo CA with two Members:

BOEING

Core Competency, Cutting Edge R&D Infrastructure in Four Laboratories:

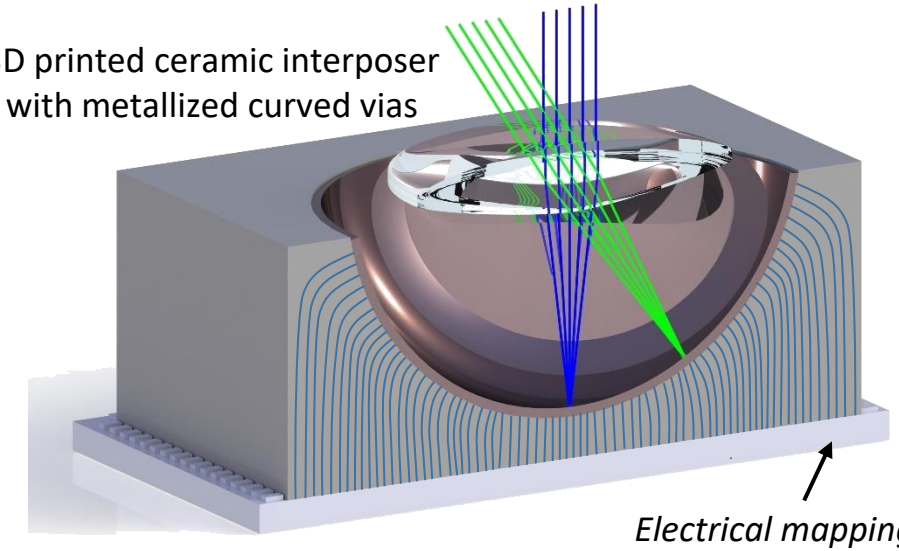
- Information and Systems Sciences
- Sensors and Electronics
- Microfabrication Technology
- Materials and Microsystems

Excellent Innovation Track Record: >1700 patents issued in last 20 years

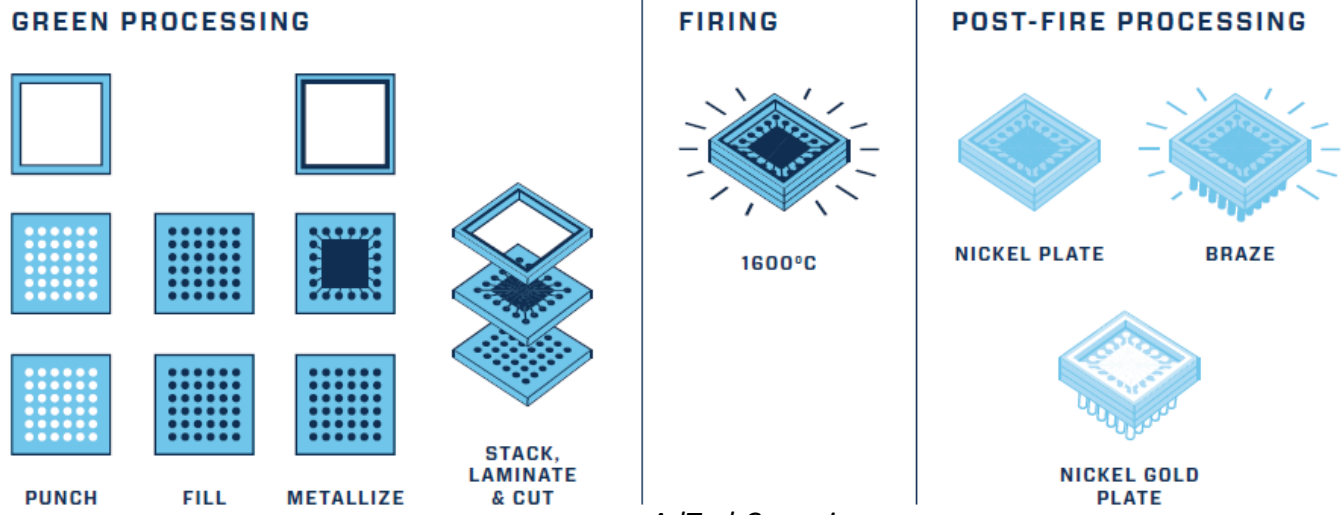
Government R&D contracts make up more than 75% of HRL's research

Motivation: Microprinting of Ceramics for Microelectronic Packaging

3D printed ceramic interposer with metallized curved vias



Electrical mapping to flat, unmodified ROIC



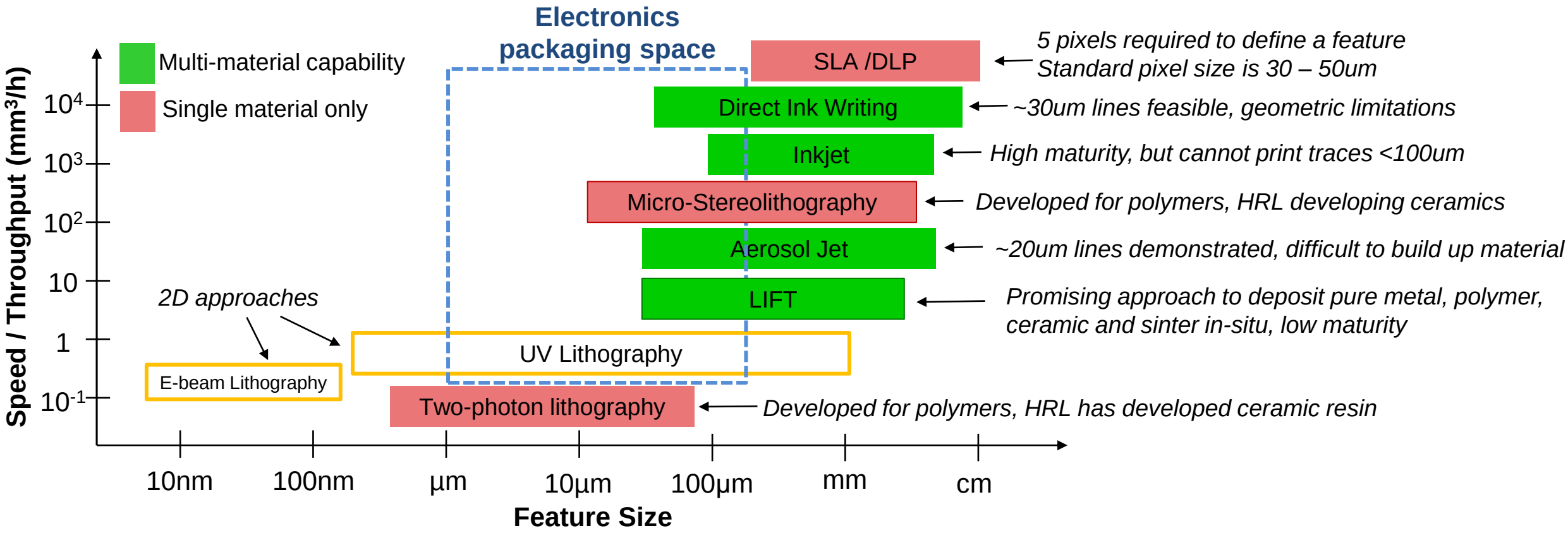
AdTechCeramics.com

- 3D designs are limited by the conventional ceramic packaging technology which are restricted by etching and stacking laminations.
- Electrical routing with complex curves, like in this ceramic interposer, are not possible with SOA technology.
- Micro 3D printing technology would enable advanced compact designs and faster design iterations to boost performance and reliability

HRL is developing technology to enable advanced designs via ceramic 3D printing

	Current Practice	3DP Approach
Min. feature size	~100 um	~10 um
Feature shape	Horizontal and vertical	Any angle & curved
Sintering temp	LTCC: 900C HTCC: 1600C	PDC: 750C
Shrinkage	~20%	15 – 25%
Lead time	5 – 6 months	<1 month
CTE	8 (Alumina)	Tailorable 1 – 8
Trace metal	W for HTCC	Ag (3X conductivity)

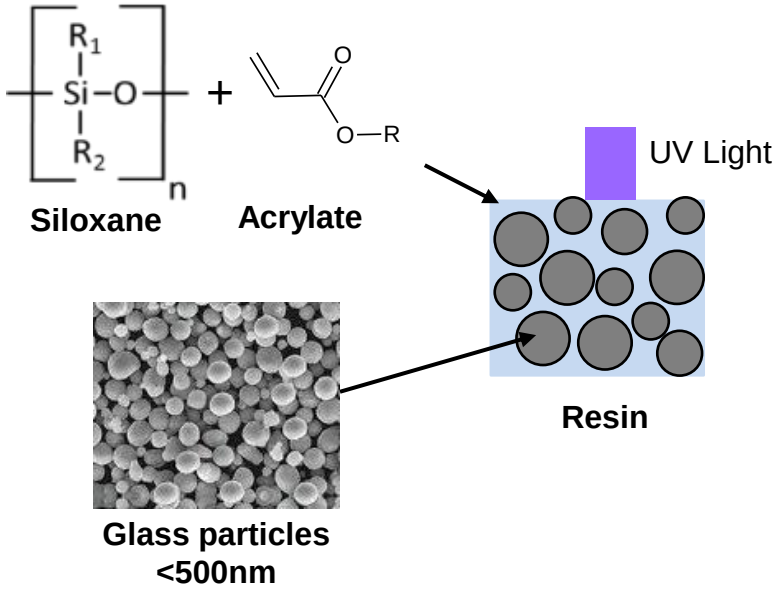
Additive Manufacturing at Small Length Scales



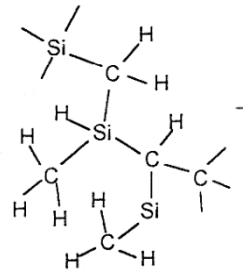
Micro-Stereolithography selected to print ceramic interposer

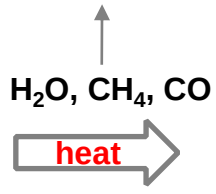
Strategy: print holes in ceramic and fill with metal afterwards

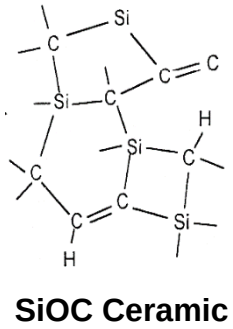
3D Printing of Polymer Derived Ceramics



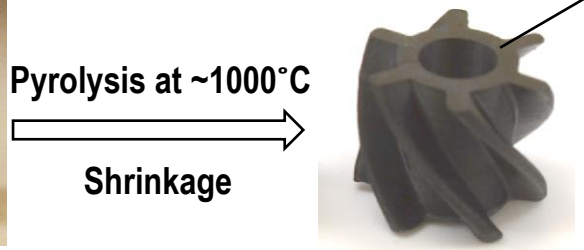
Eckel et al. *Science* (2016)



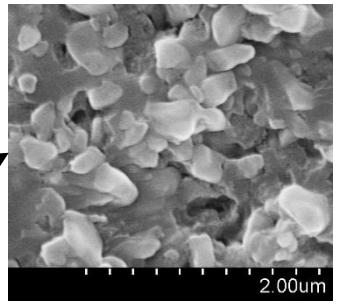





Pre-ceramic polymer



Polymer-derived ceramic



Microstructure (SEM)

Hundley et al. *Additive Manufacturing* 18, 95 (2017)

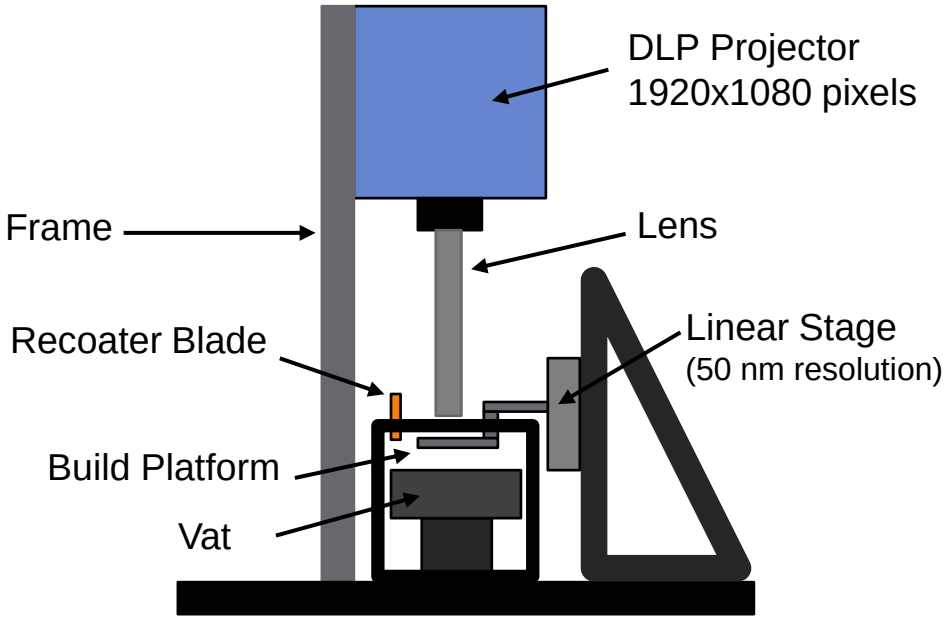
Advantage of particle addition:

- Decrease shrinkage
- Increase toughness & strength

O'Masta, et al. *J. Am. Ceram. Soc.* (2020)

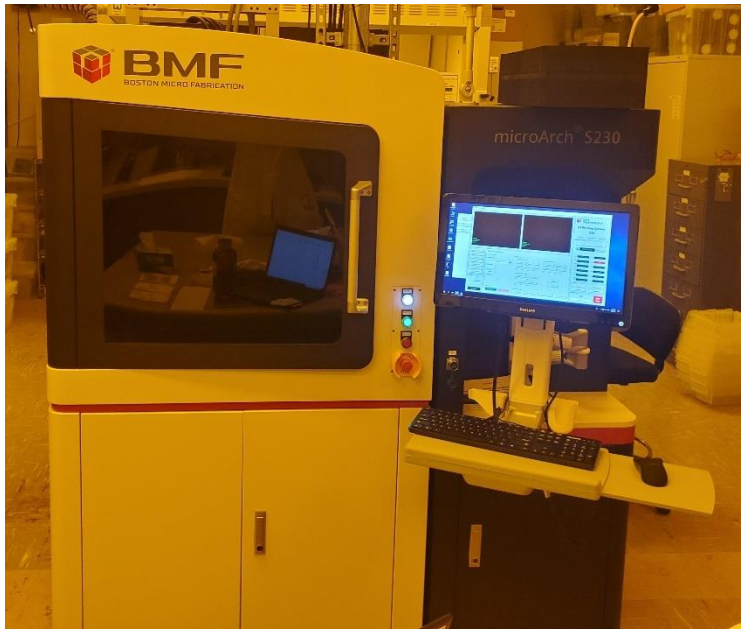
HRL Innovation: UV curing of preceramic monomers
→ enables low viscosity resins for high resolution 3D printing of ceramics with SLA & DLP printers

Micro Projection Stereolithography



- *C. Sun, N. Fang, D. M. Wu, X. Zhang, Sens. Actuators A (2005)*
- *X. Zheng et al., Rev. Sci. Instrum. 83, 125001 (2012)*

Boston Micro Fabrication S-230



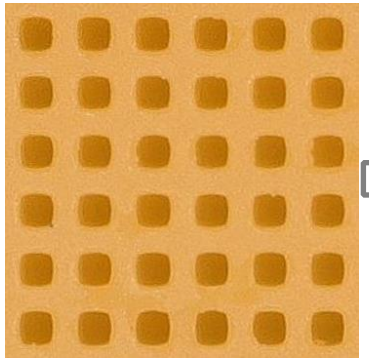
- Lens system: 2x2μm pixels
- FOV = 3.8x2.2 mm
- 50x50x50mm build area
- System requires tiling to meet build area requirements
- Layer thickness = 2 – 20 μm
- ~10μm feature resolution
- Quantitative laser leveling
- Mechanical layer flattening
- Resin displacement compensator

- HRL purchased first system
- Designed for printing polymers
- HRL developed print parameters for preceramic resins

Advances in Micro Projection Stereolithography enable 2μm resolution over large areas (>4 in^2)

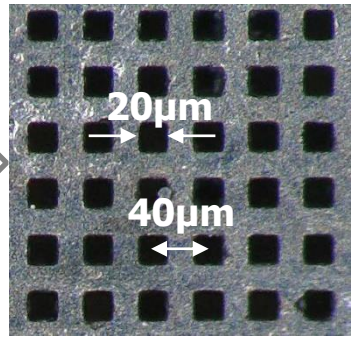
Achieving High Resolution

As-printed Flat Interposers

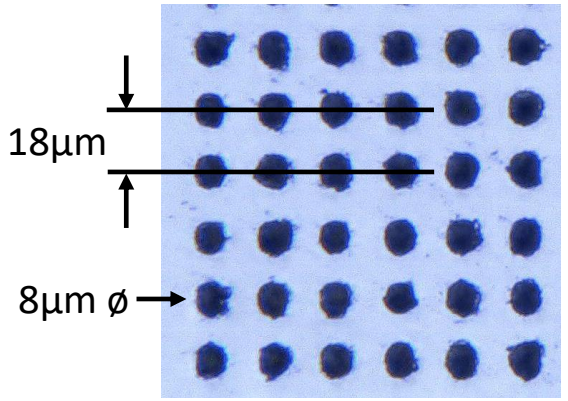


Green Part

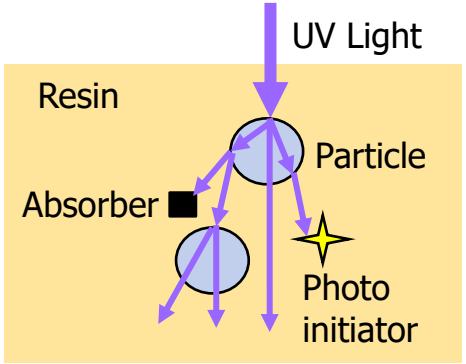
heat



After conversion to ceramic

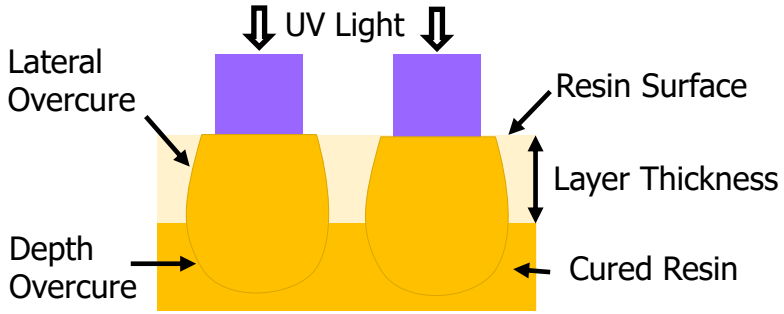


3D printed vias in ceramic



UV Curing Mechanism

- Pre-ceramic resin reinforced with index-matched nanoparticles (<500nm) and low viscosity developed

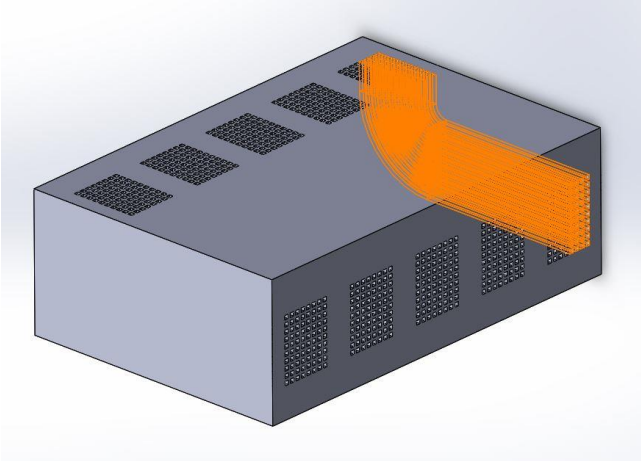


Overcure Effect

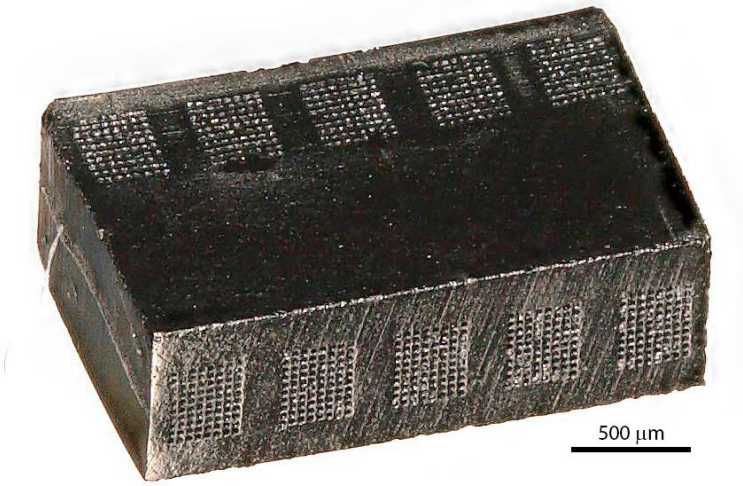
Minimum via diameter of 8µm and pitch of 18µm achieved in 3D printed ceramic with BMF S-230 printer

Could go ~2X smaller by reducing pixel size from 2µm to 1µm

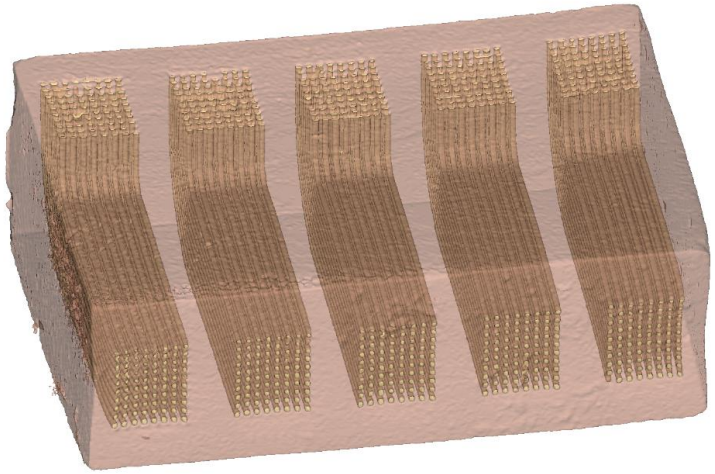
3D Printing of Curved Vias



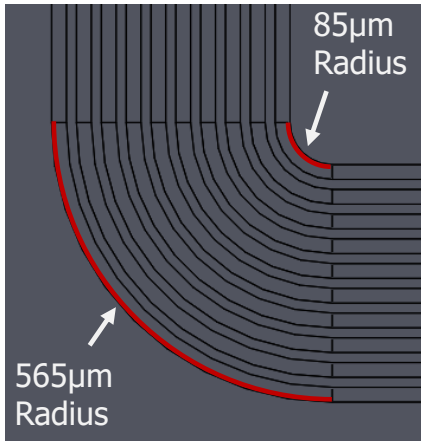
CAD File



3D printed ceramic part
with 20um ⌀ vias at 40um pitch



X-ray micro CT of ceramic part

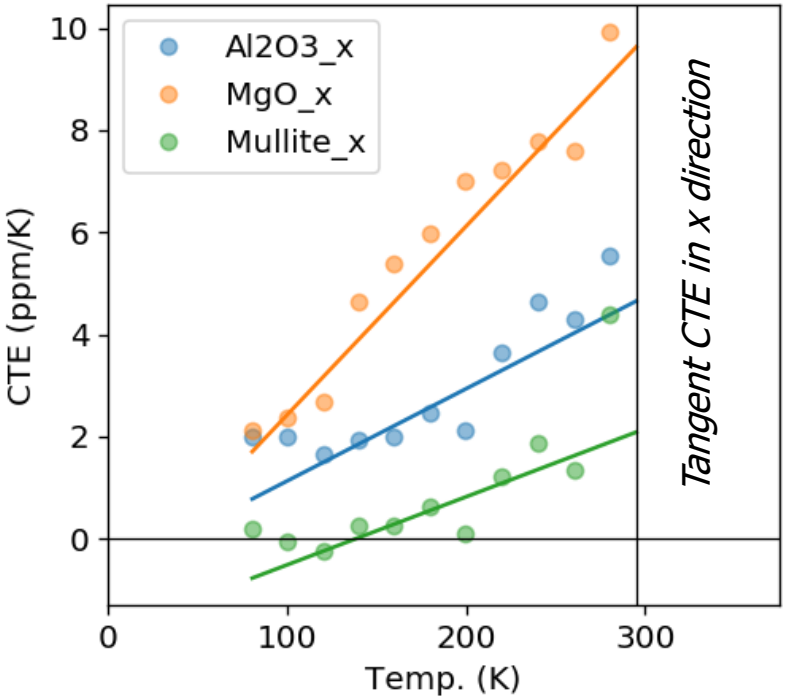


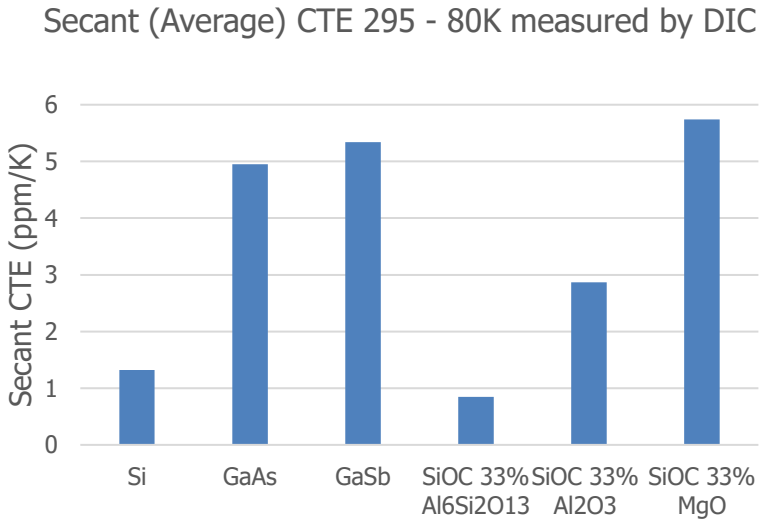
Breakthrough in ceramic packaging technology:

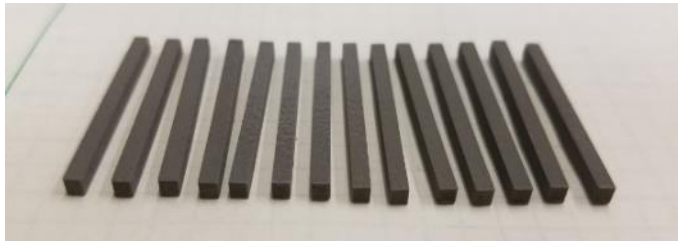
Curved vias successfully printed and metallized

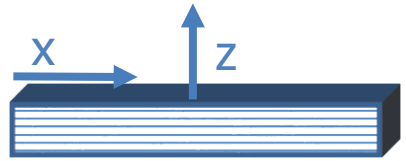
Cross-section after metallization
(polishing off-axis to vias)

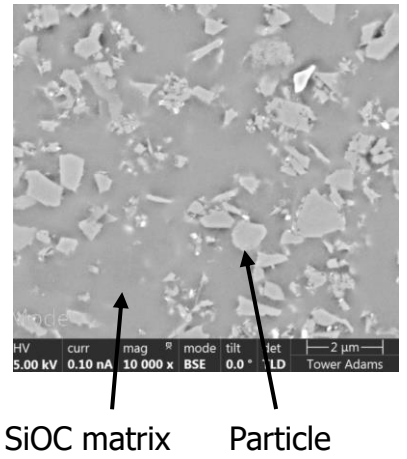
Tailoring CTE of 3D Printed Ceramic











- Selected MgO, Al_2O_3 and $Al_6Si_2O_{13}$ with CTE = 10.8, 7 and 5 ppm/K at 25˚ C
- Suspended 15 vol% particles (D_{50} = 0.6µm) in preceramic resin
- 3D printed test bars, after firing and shrinkage: 33 vol% particles in SiOC ceramic
- CTE measurement at low temperatures with ARAMIS System for Digital Image Correlation (DIC)

CTE of 3D printed ceramic can be easily tailored by addition of particles

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Published in:

Z. Eckel et al. *Science* 351 (2016)
J. Hundley et al. *Addit Manuf.* 18 (2017)
M. O'Masta et al. *J Am Ceram Soc*. 103 (2020)

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