Advanced Manufacturing

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NOTE: The original presentation includes one or more animations/videos; please email betterplants@ee.doe.gov to request a copy of the original, large file.

Advanced Manufacturing at LLNL

- Direct Ink Write for materials with controlled mechanical properties
  - Simple cubic vs Face-centered tetragonal
- Structural Supports
  - Light weighting while maintaining strength and stiffness
    - Carbon Fiber reinforced polymer structures
    - Lattice structures
- Target Fabrication for High Energy Density Facilities (National Ignition Facility, OMEGA, Gas Guns)
  - Additive Manufacturing (AM) is extensively used for prototyping and tooling
    - Currently precision is limiting the use of AM for the physics packages
- Wrap-up

We aim to replace foams with ordered cellular materials

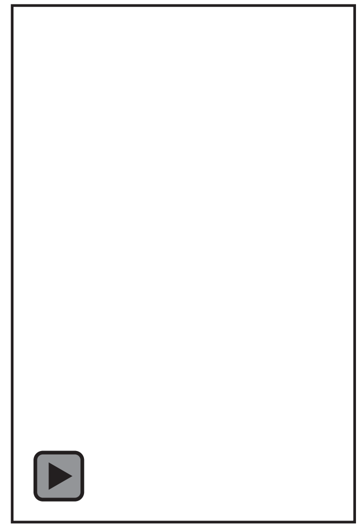
Foams are limited in their performance due to lack of structural control

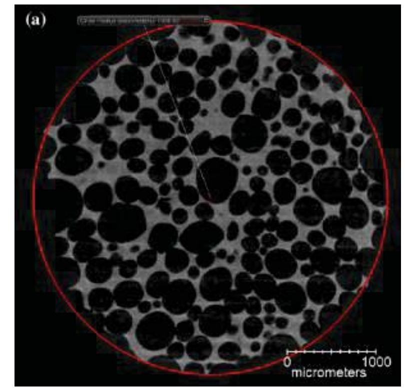
Foams are designed to:

- Protect against vibrations
- Distribute and relieve stress
- Maintain relative positioning
- Mitigate the effect of size variation

Foams are also *stochastic*:

1. Difficult to control mechanical properties
2. Exhibit non-uniform properties
3. Little control over directional properties
4. Difficult to develop predictive models

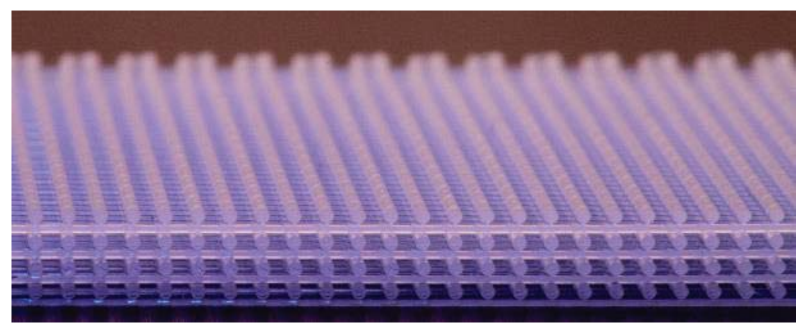




Courtesy Brian Patterson, LANL

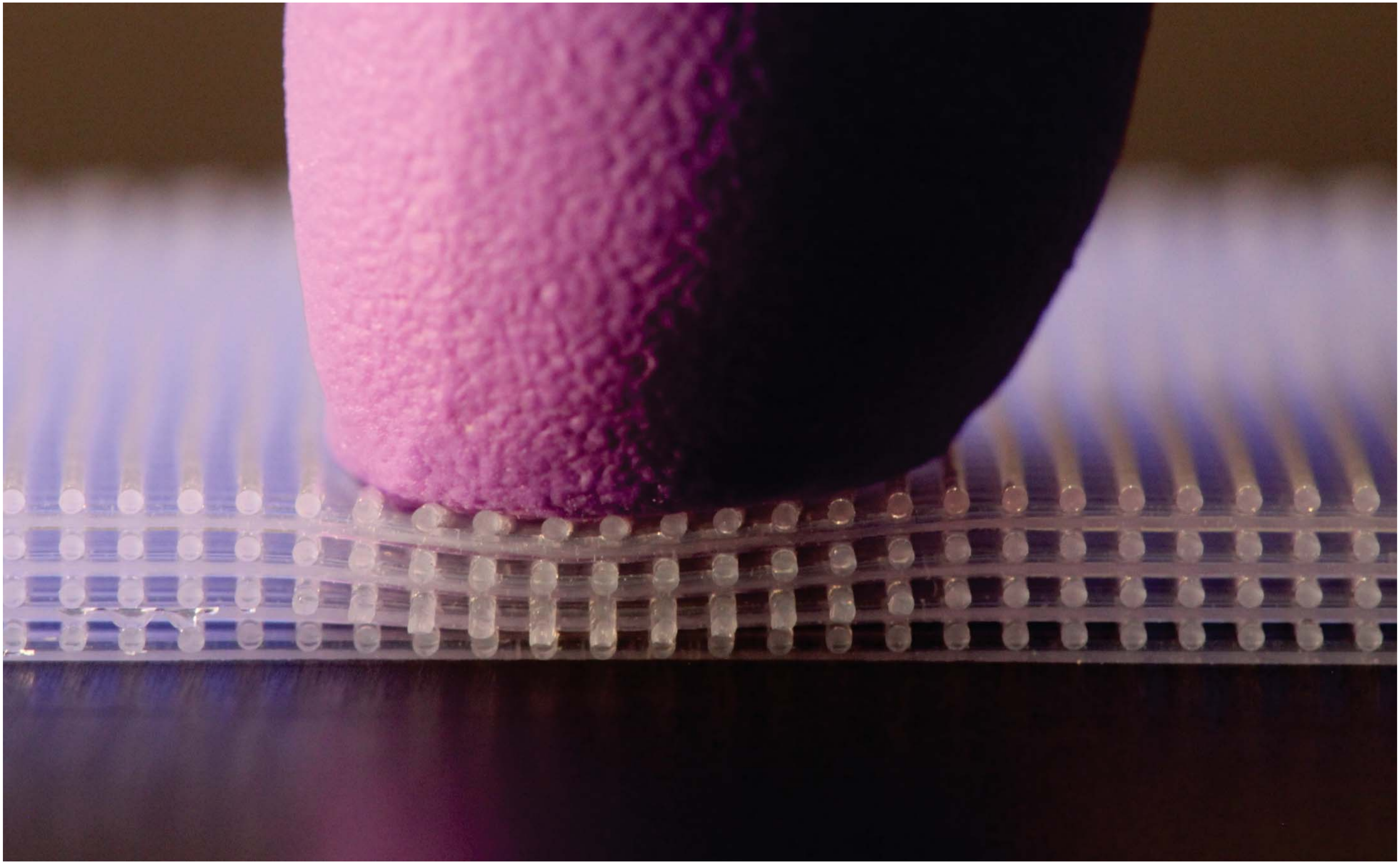
Ordered **cellular materials should:**

1. Enable better control of mechanical properties
2. Exhibit more uniform properties
3. Enable better control over directional properties
4. Enable a predictive modeling capability

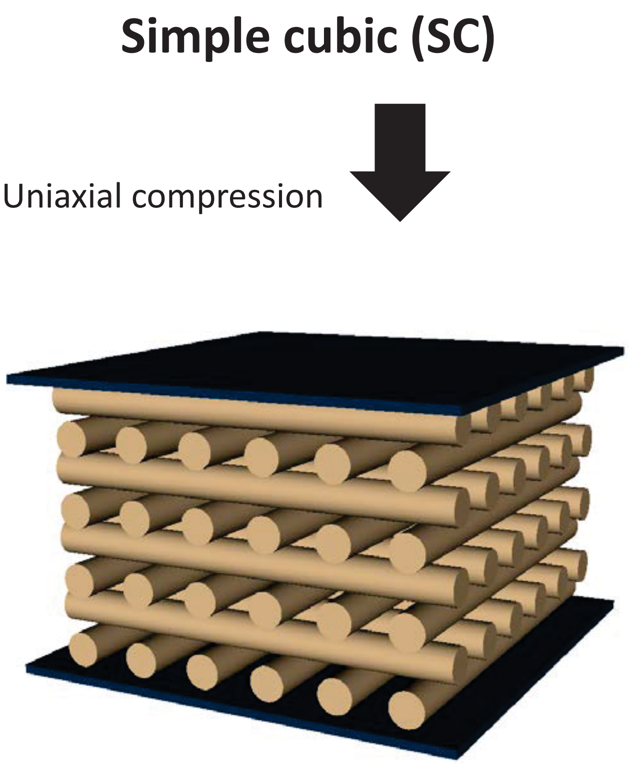


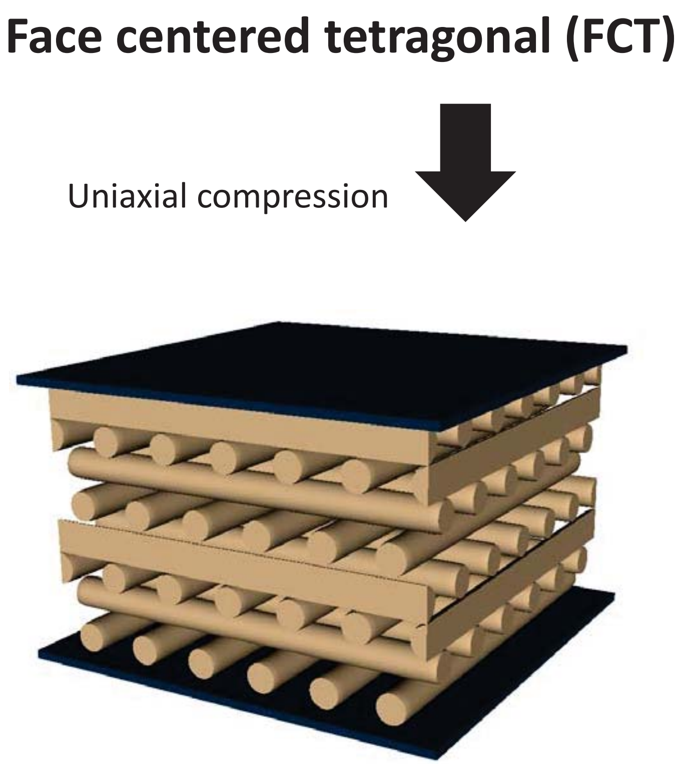
We print many flexible, stretchable, soft materials

We create our own inks with custom properties



Two microarchitectures patterned in silicone have designed mechanical properties

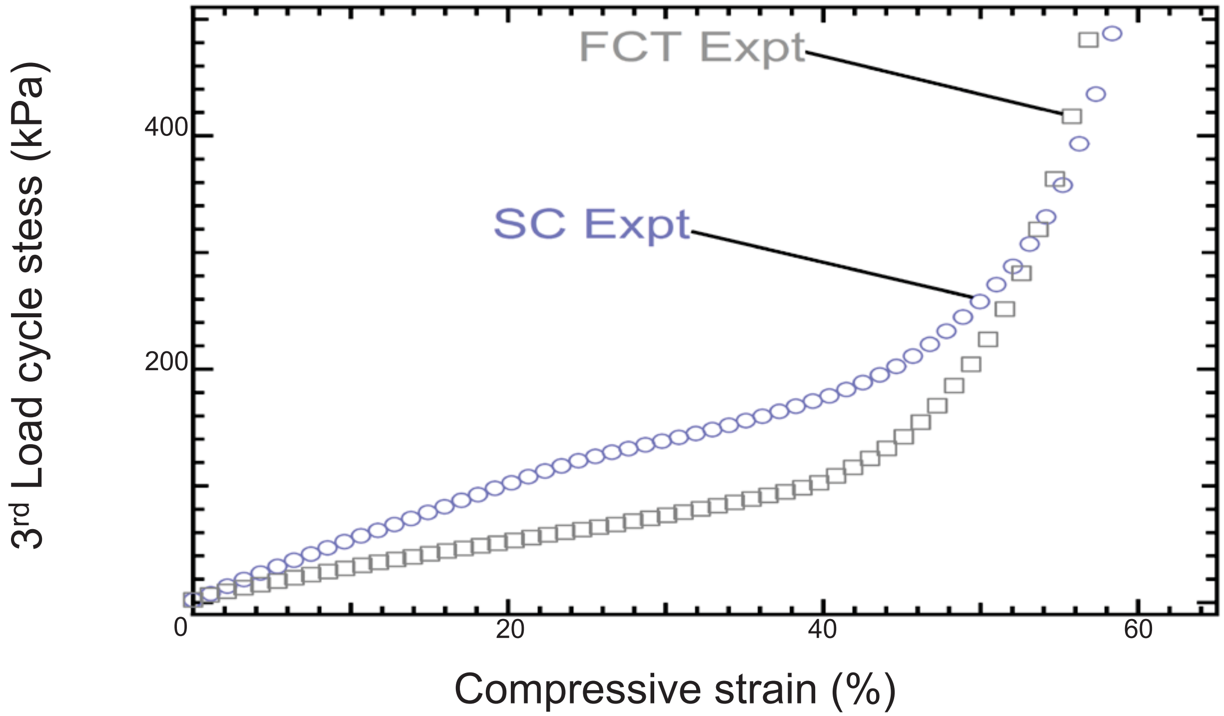




E. Duoss, et al., *Advanced Functional Materials*, 2014

Two microarchitectures patterned in silicone have designed mechanical properties

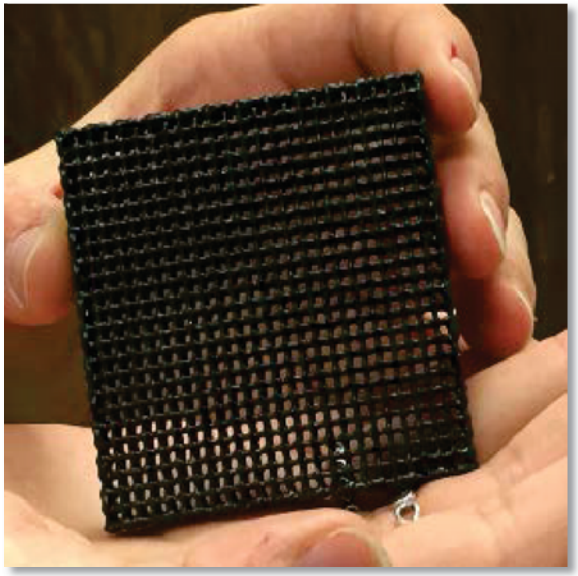
Architecture-dependent
uniaxial compression behavior



E. Duoss, et al., *Advanced Functional Materials*, 2014

3D structures can also be built

Direct Ink Write (DIW) printing technology allows us to build structural supports by controlling carbon fiber alignment in 3D



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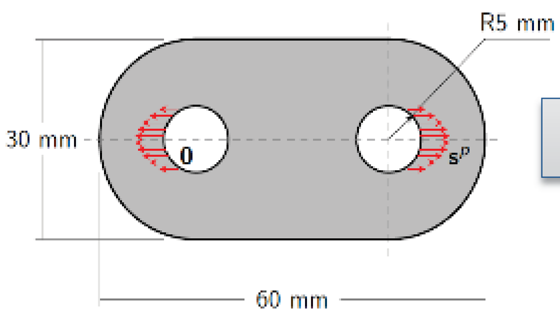
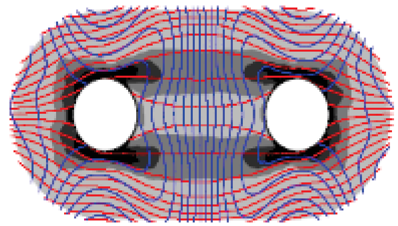
We rationally design optimal and printable part microstructures



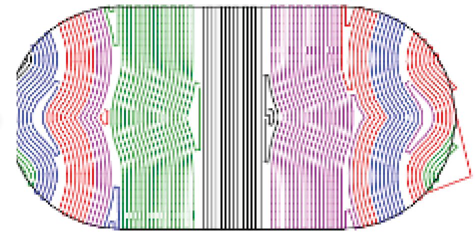
Design test case

Optimizer



Mathematically optimized solution

Toolpath planner

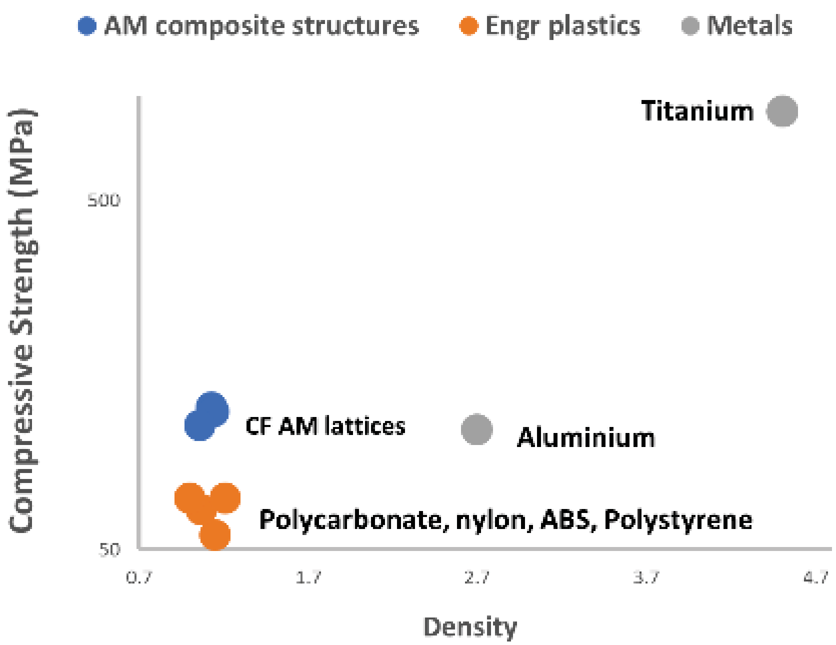


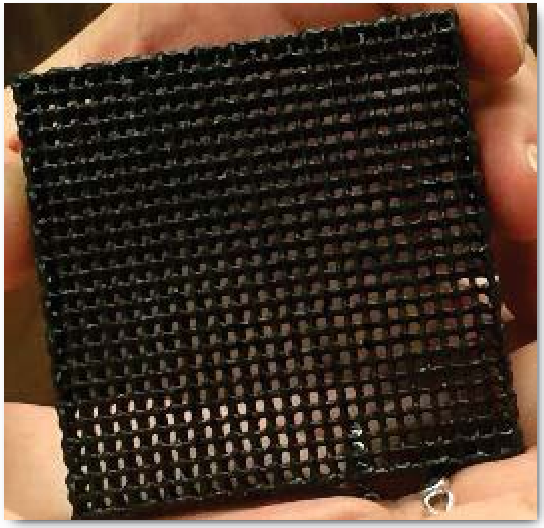
Optimized machine printable structure

Realizable parts with optimized internal structure

Print!

Our printed parts outperform engineering plastics in strength

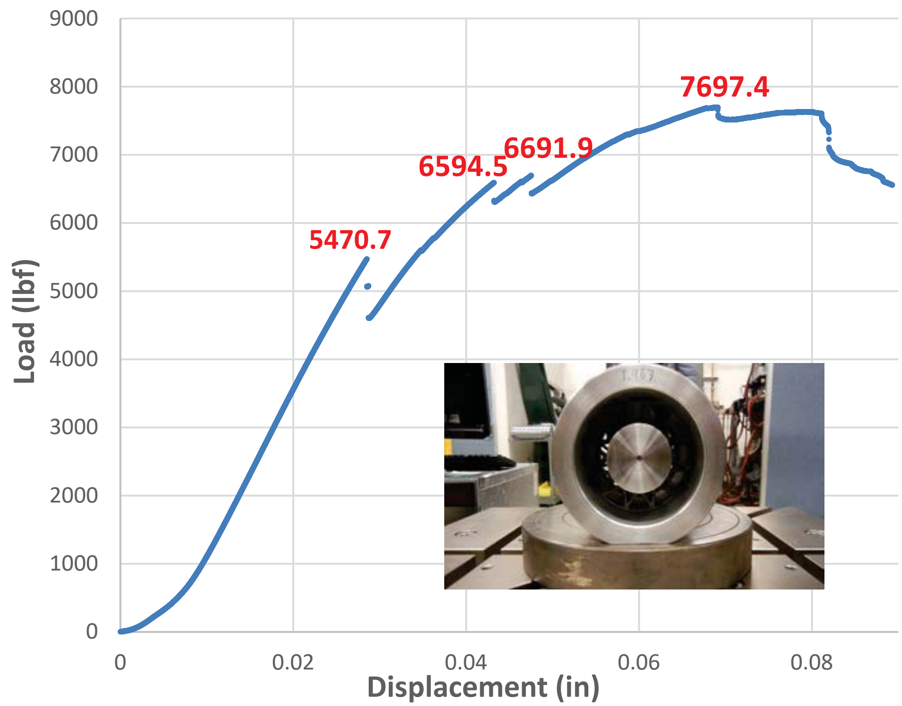




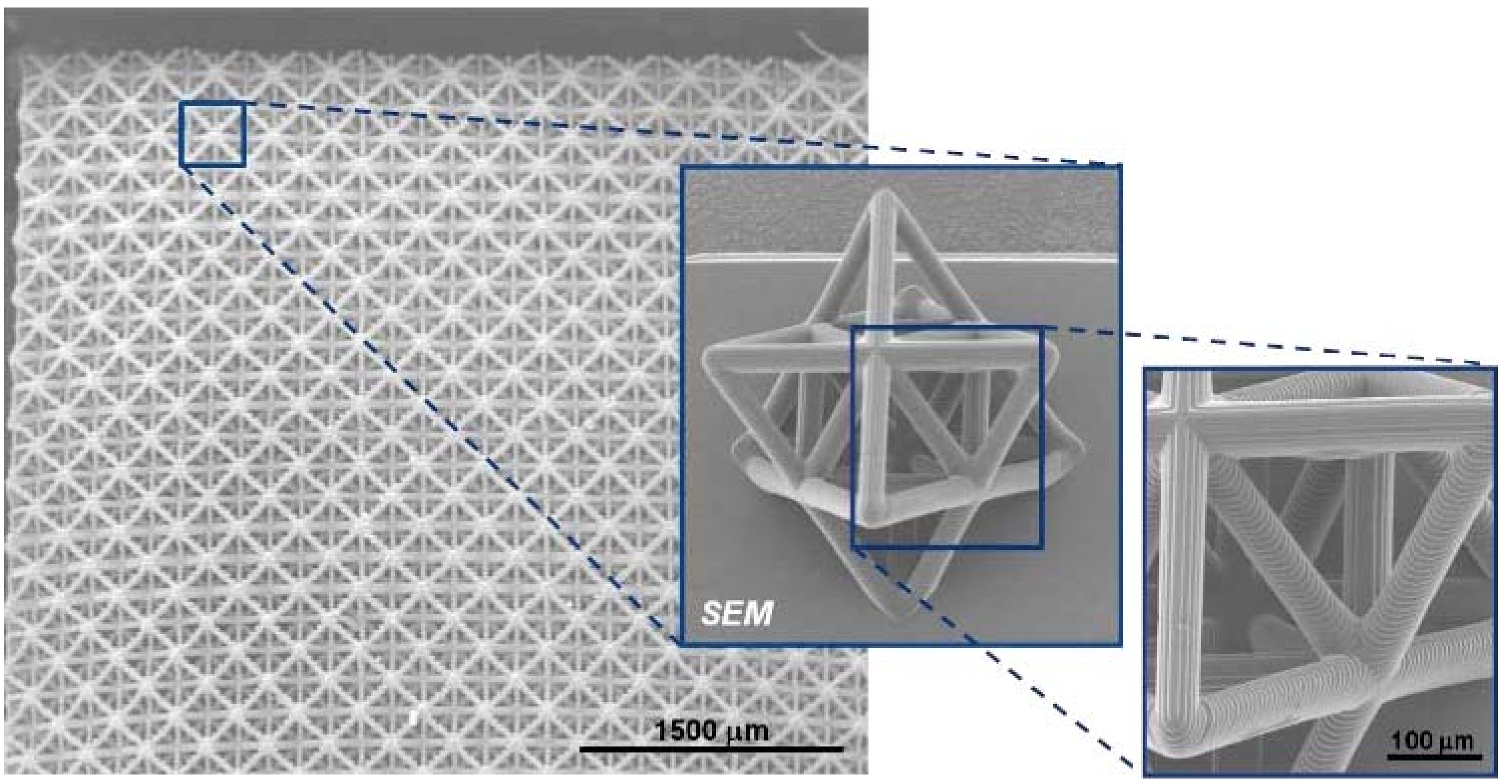
Carbon fiber reinforced structural polymer components

Structural variants can be rapidly assessed

Printed parts can be quickly evaluated



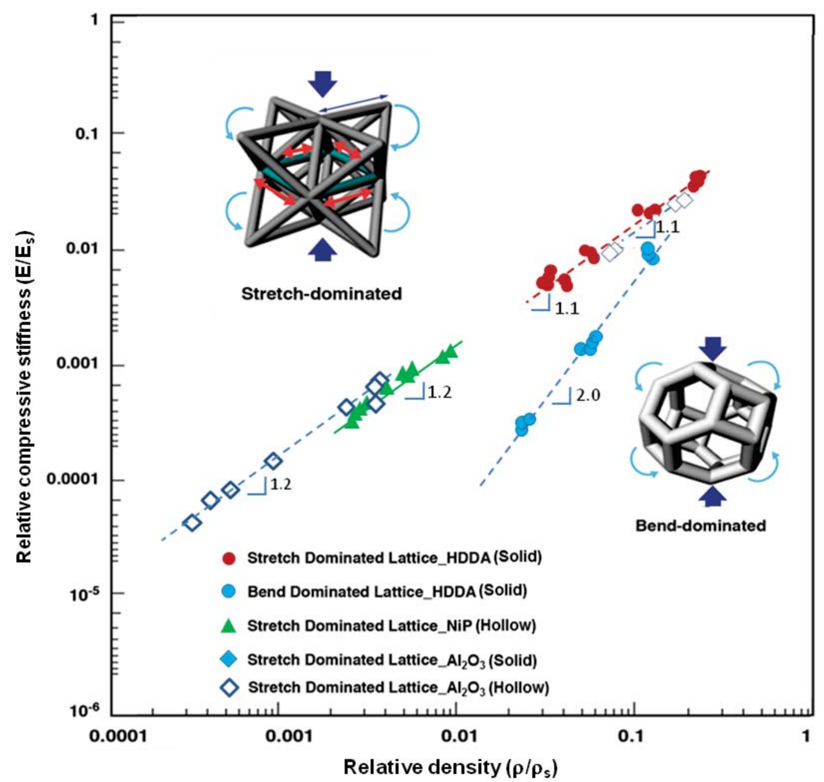
The Octet Truss microlattice (stretch dominated) has been fabricated with microstereo lithography and compared to bend dominated architectures



X. Zheng*, et al.*, *Science,* 2014

The expected structure-property relationship for stretch dominated structures has been demonstrated

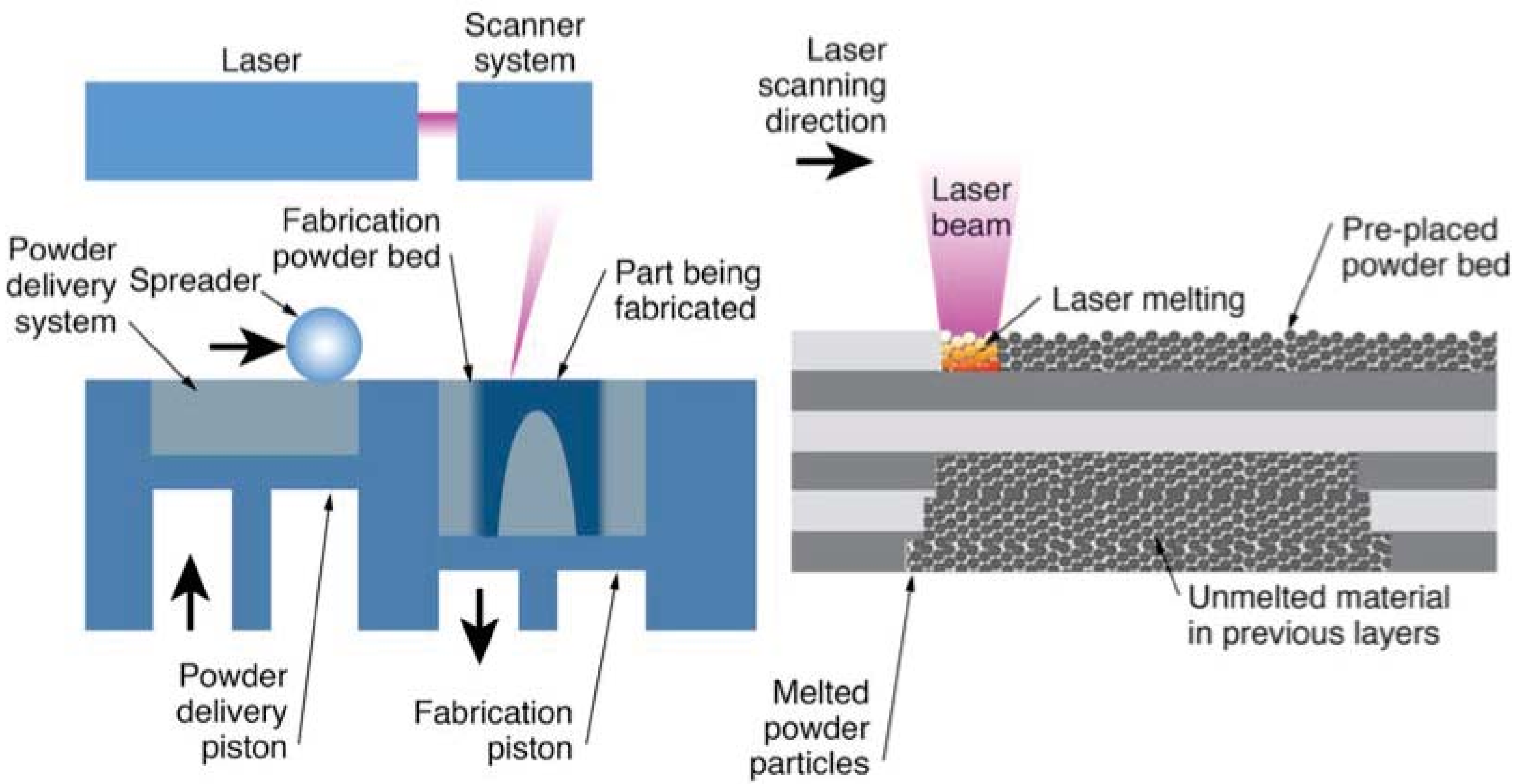
This mechanical material has orders of magnitude higher stiffness than other porous materials in this low density regime.



X. Zheng, *et al., Science,* 2014

Can we use this with metals ?

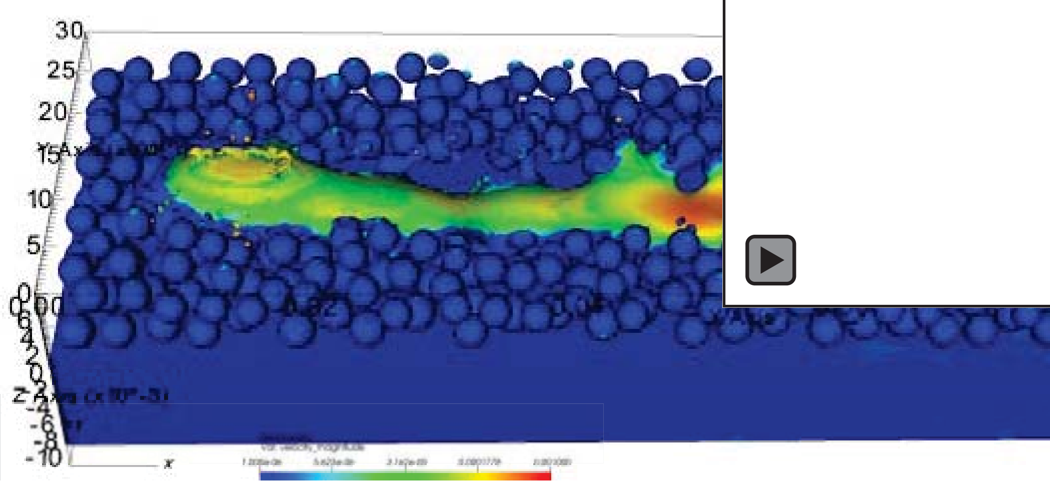
Laser Powder-Bed Fusion or Selective Laser Melting



Modeling and simulation combined with advanced diagnostics are a powerful combination

- At high scan speed and high power, forward 'snowball' ejection is observed *(~2.5 m/s)*
- Faint vapor trail more visible at higher power

Simulations in ALE3D

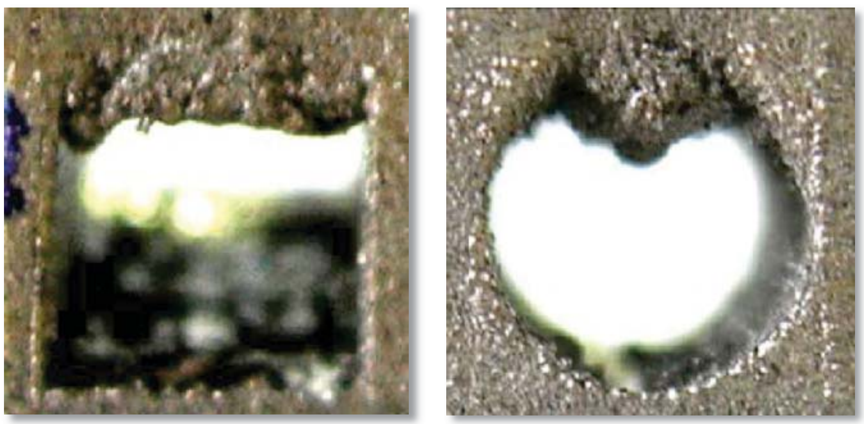


Approach: Mesoscopic 3D simulation of metal powder bed fusion using ALE3D

Laser power	200W
Laser scan speed	1500mm/s
Substrate dimensions	1000x300x50µm^3

Physics	What is the driving physics?
Pore Generation	How do pores form and evolve?
Recommendations	Guidance for better parameter choice?

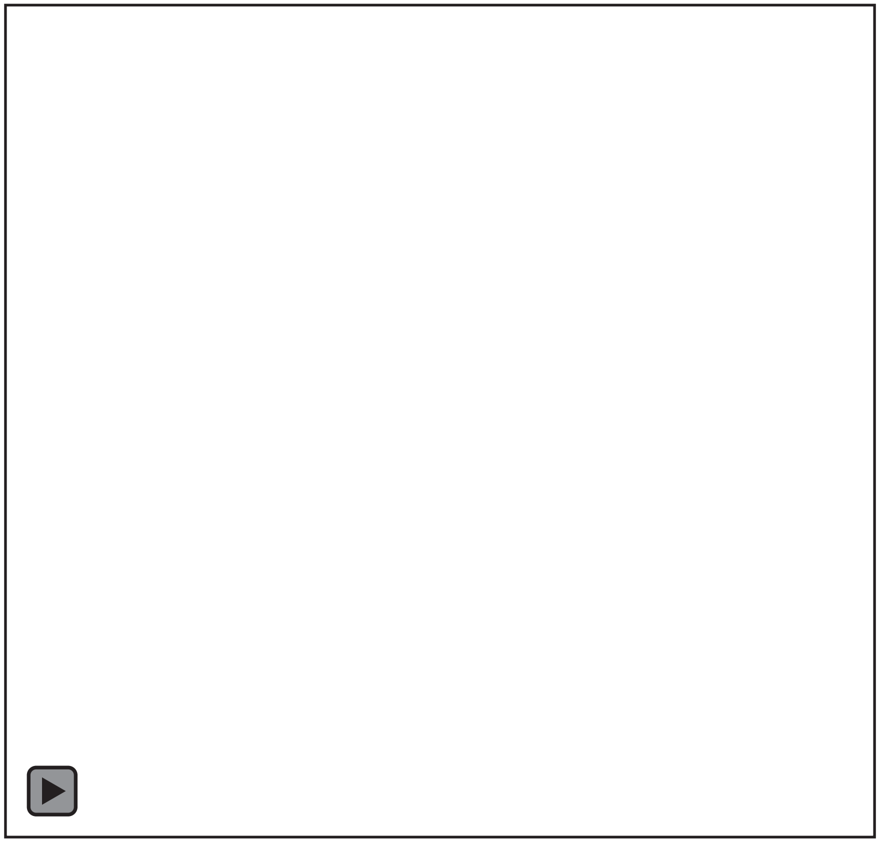
The Diablo part scale model predicts significant increase in temperature and melt pool volume in an overhang region

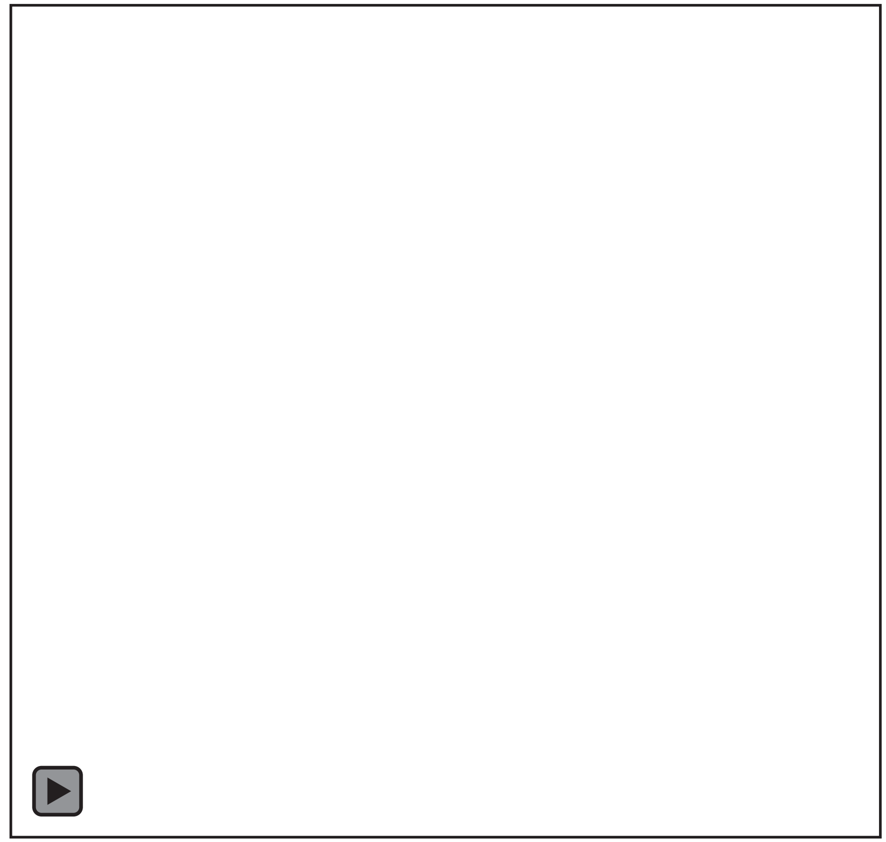


Experimental observation of "dross" formation in overhang regions

Hodge, N.E., Ferencz, R.M., Solberg, J.M., 2014. Implementation of a thermomechanical model for the simulation of selective laser melting. Comput Mech, 1-19.

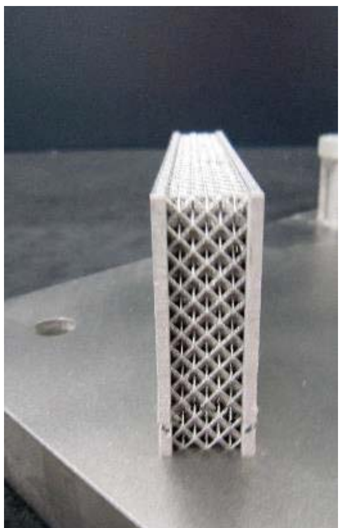
By changing the power, we can mitigate the excessive melting in the overhang



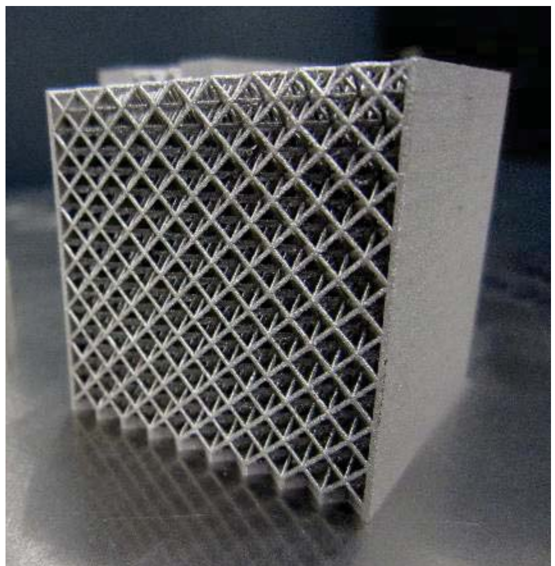


Modeling and simulation indicate that feed forward could be successful

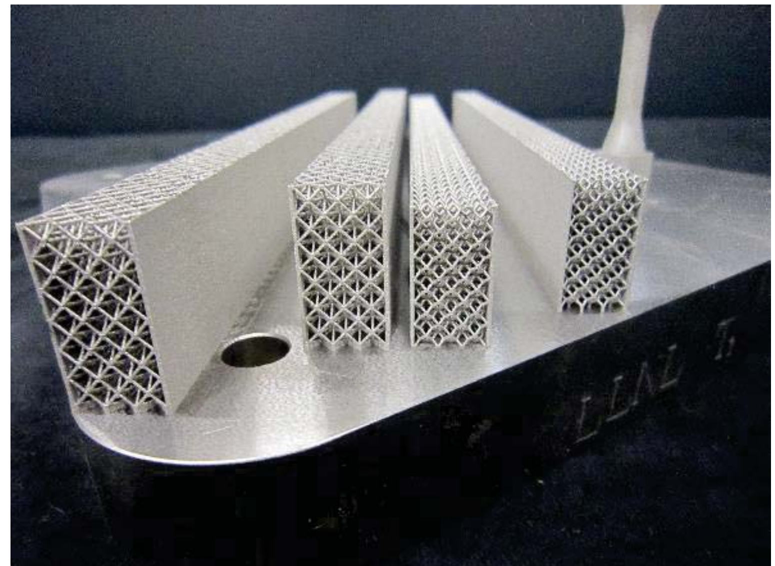
Shear, Compression, and Bending Samples in process of being tested



Shear Sample



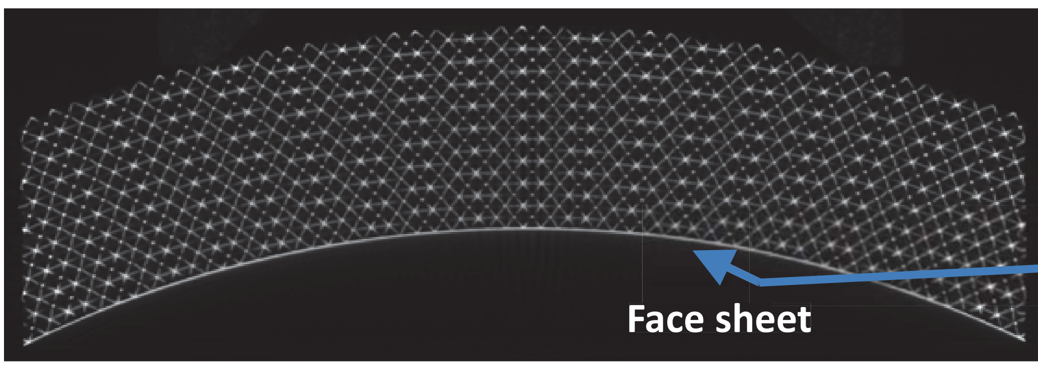
Compression Sample

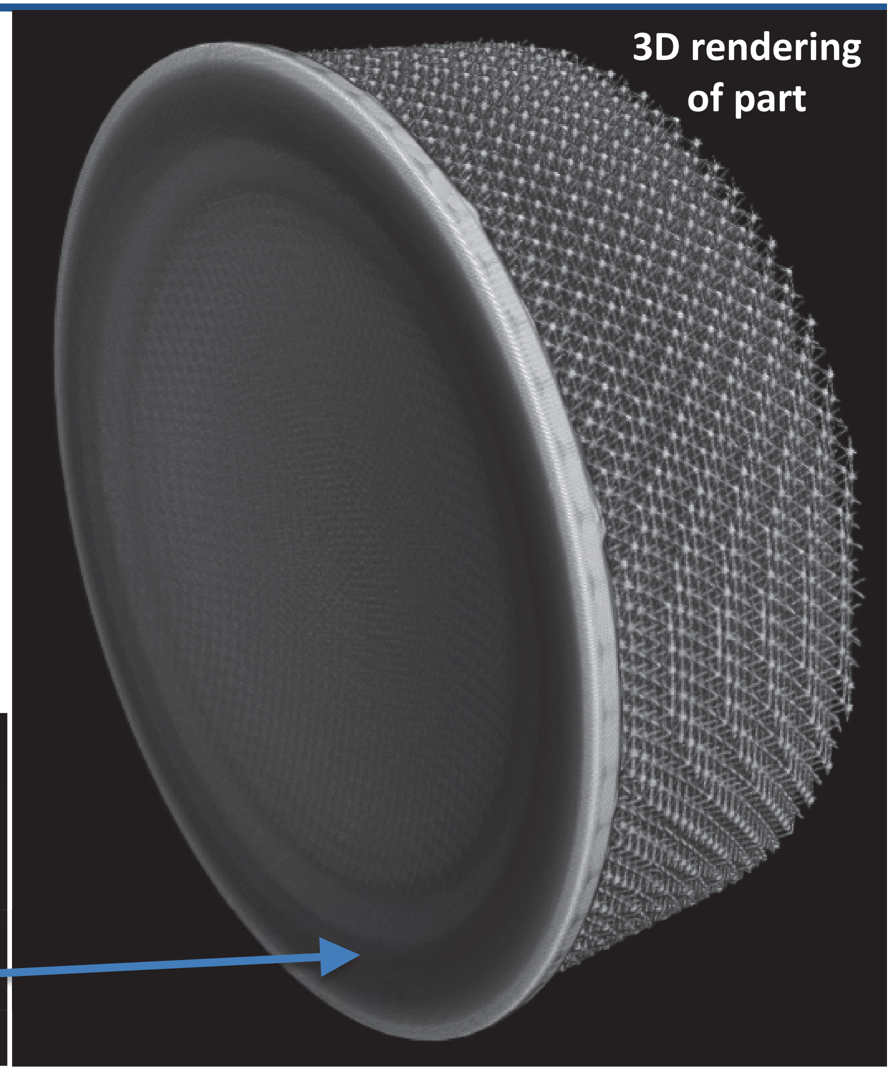


Bending Samples

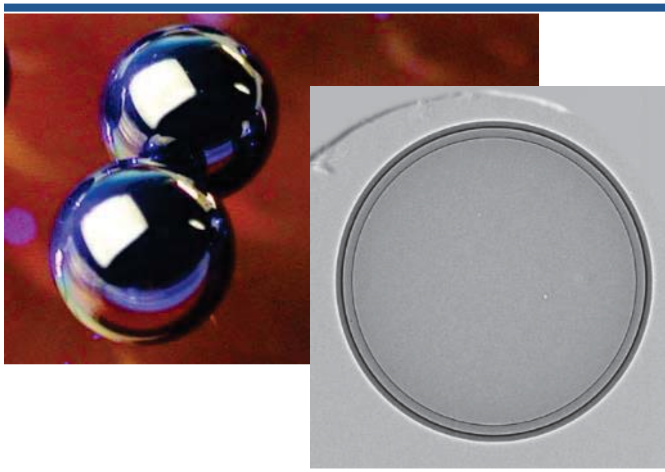
The AM Lattice parts

- Material:
  - Titanium Ti-6Al-4V or Ti-5Al-5V-5Mo-3Cr
- Geometry
  - Conformal octet truss to a face sheet (dodecahedral structure insufficiently strong)
  - 0.35-mm strut diameter
  - 0.35-mm face sheet thickness
- Fabricated on a Concept Laser M2 machine using selective laser melting

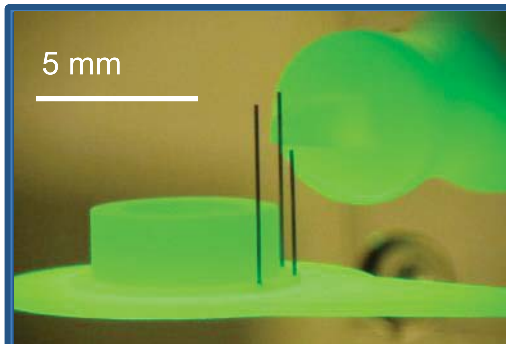




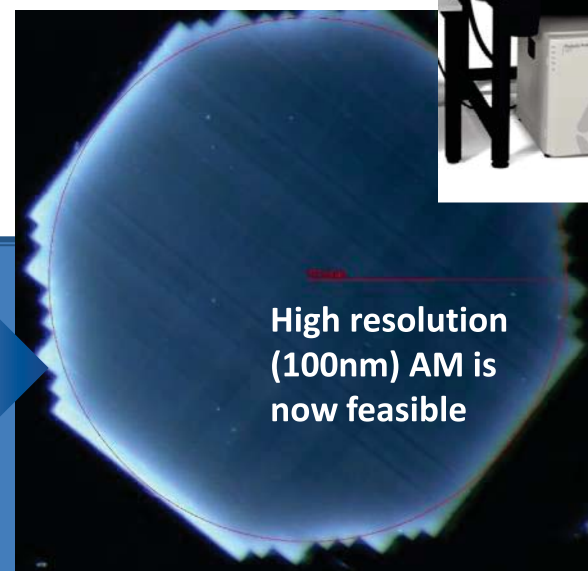
AM has the potential to transform target development



Developing a new target platform may take 10 years from conception to reality



From process testing towards enabling / high value added AM target components

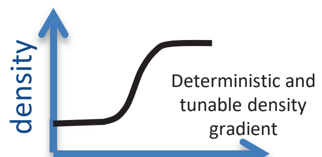


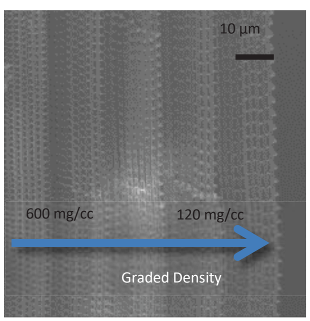
High resolution (100nm) AM is now feasible

Unique, high performance targets require functional materials (metals, ceramics, plastics) with complexities (morphology, composition, and integration) significantly beyond the current state-of-the-art of AM

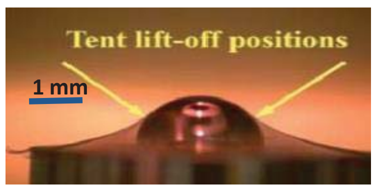
Near term targets for enabling/high value added AM target components

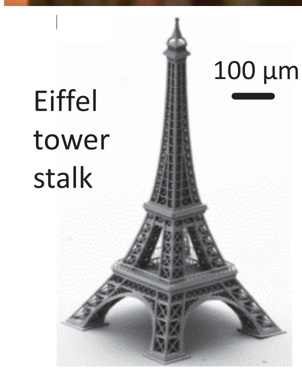
Graded density foam reservoir	Capsule support	Hohlraum	Foam-lined Hohlraums
Tailored density profiles have the potential to mitigate hydro-instability growth	15%–60% yield decrement due to tents!	Fast and inexpensive Hohlraum fabrication by metal microprinting	50% of the incident laser energy ends up in the hohlraum wall!



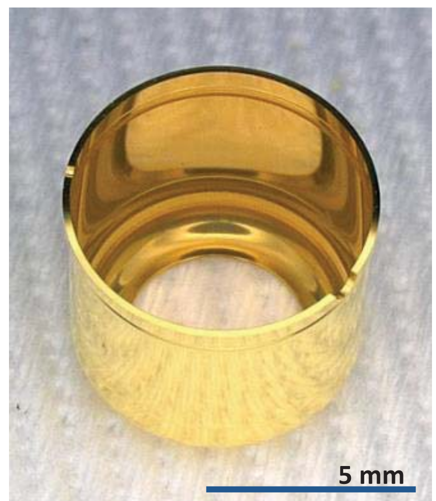


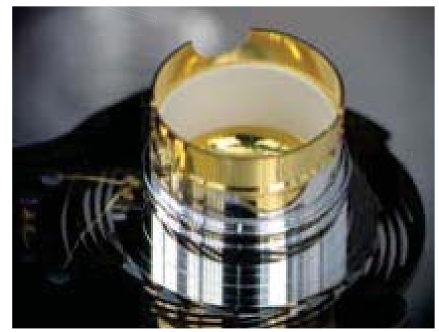
Fast and tooling-free fabrication of graded density foam reservoirs by 2PP LL (Nanoscibe)





High-strength low density architectures by DIW / PµSL combined with ALD templating





- Foam-lined hohlraums
- Foam-supported capsules

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