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3-D Direct Energy Deposition (DED) process induced material properties for the SS316L prototypes

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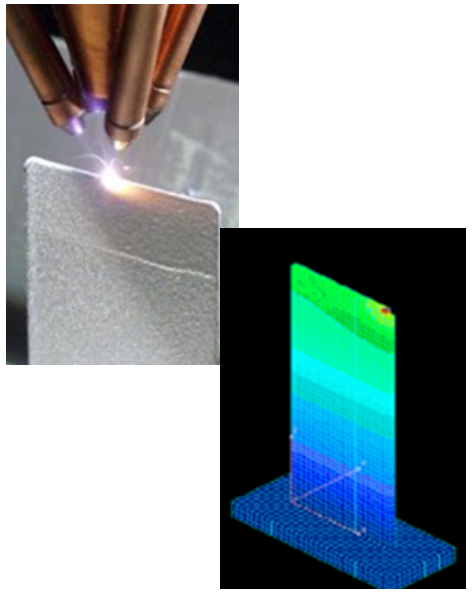
Outline

- Programmatic motivation and objective
- AM fundamentals & Science & Technology maturation activities
- Material property investigation for 3-D DED printed 316L prototypes
- Summary

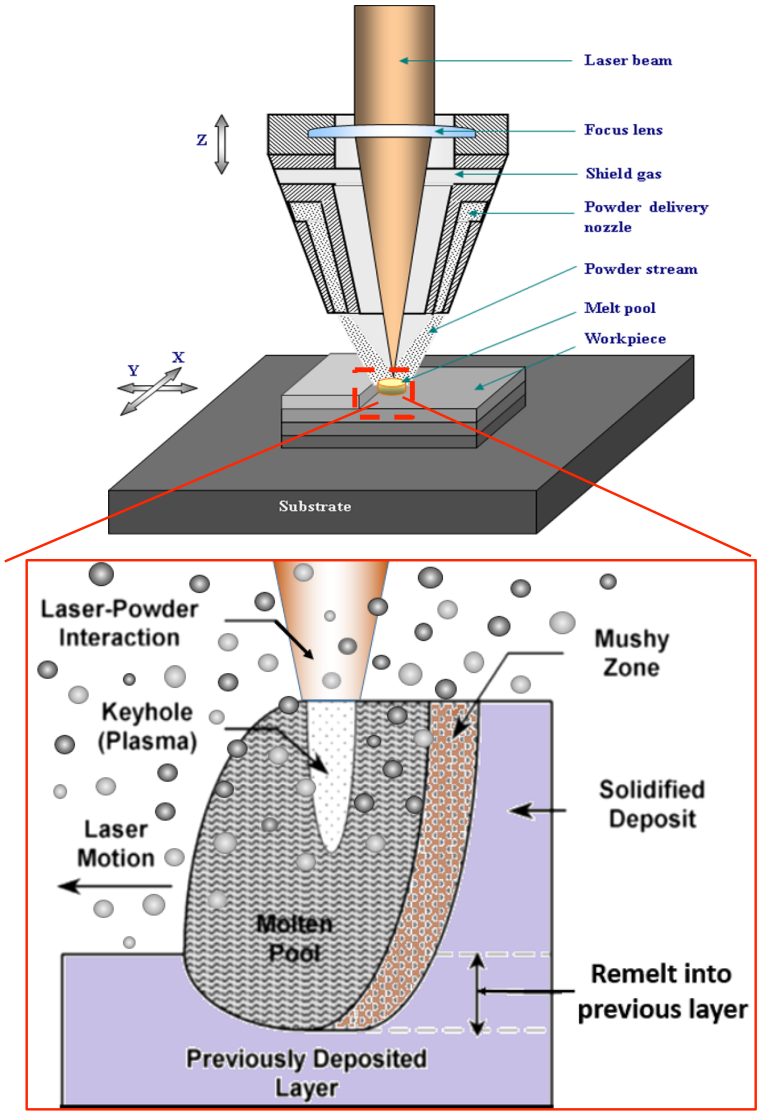
Programmatic motivation and objective

- Sandia delivers innovative energy and defense product and engineering systems with an ultimate material assurance
- AM technology offers revolutionary potential for building complex components that are impossible to build using traditional technologies

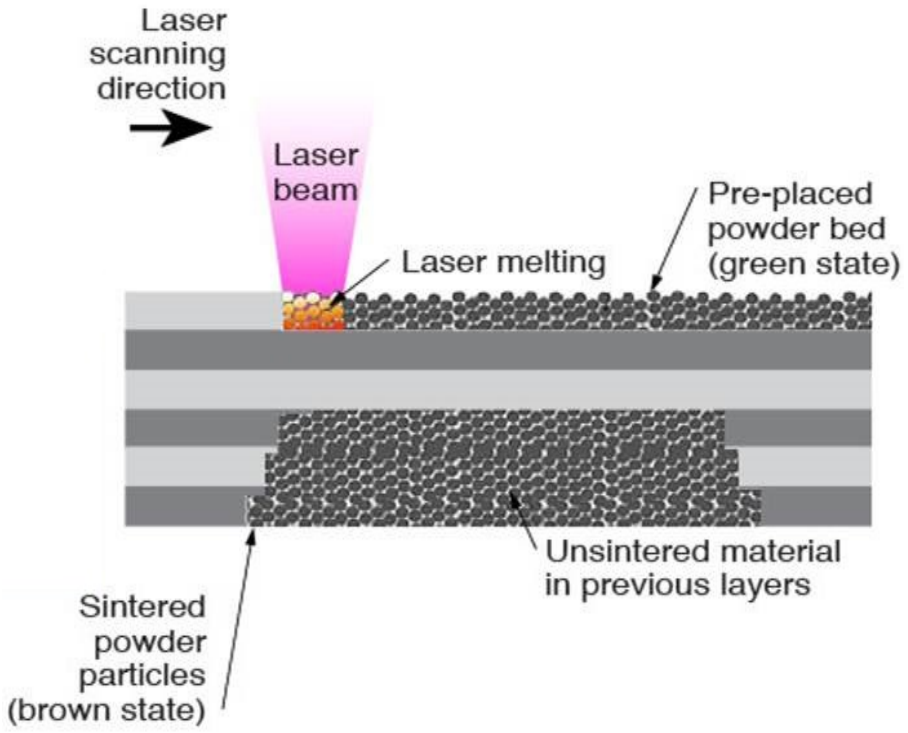


Fundamentals of DED & PBF AM printing

Direct energy deposition (DED)- Laser engineered net shaping (LENS system)



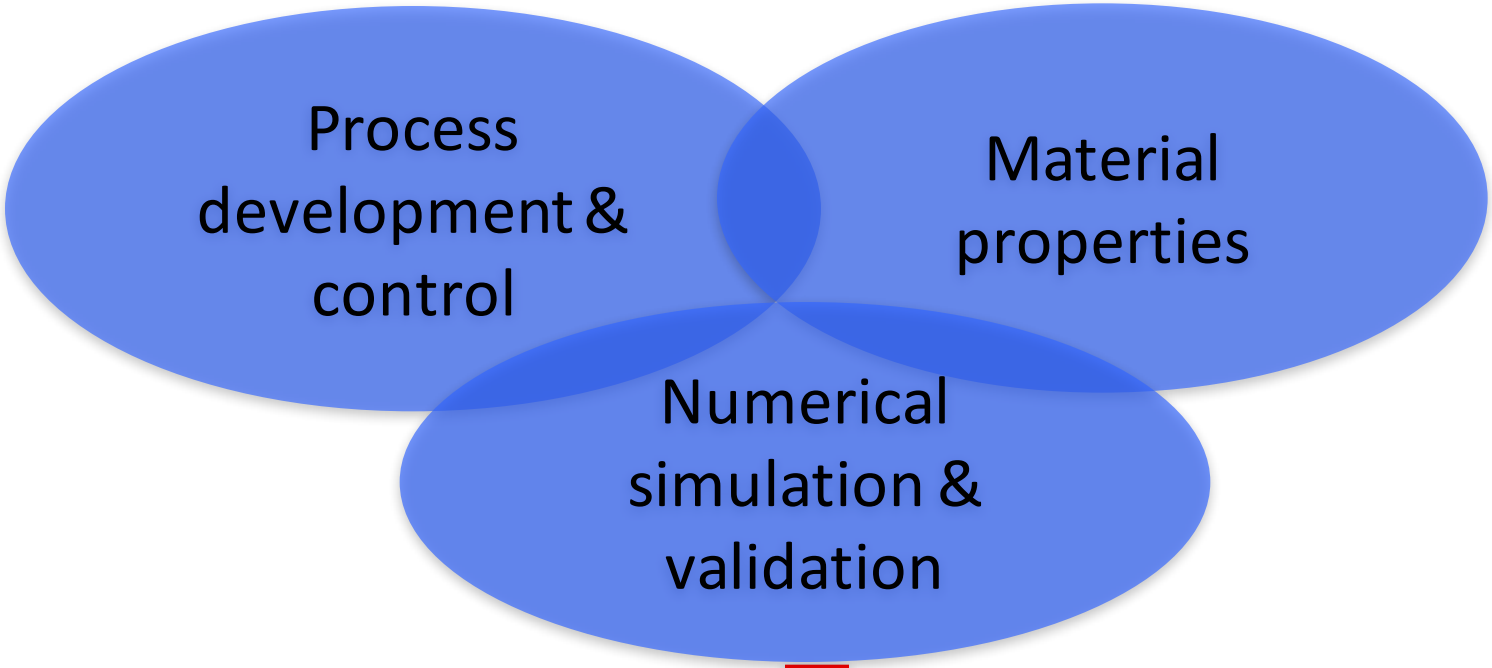
Powder bed fusion (PBF)



Both LENS and PBF involve:

- Powder melting
- Molten metal fusion
- Molten metal solidification

Science & Technology maturation activities



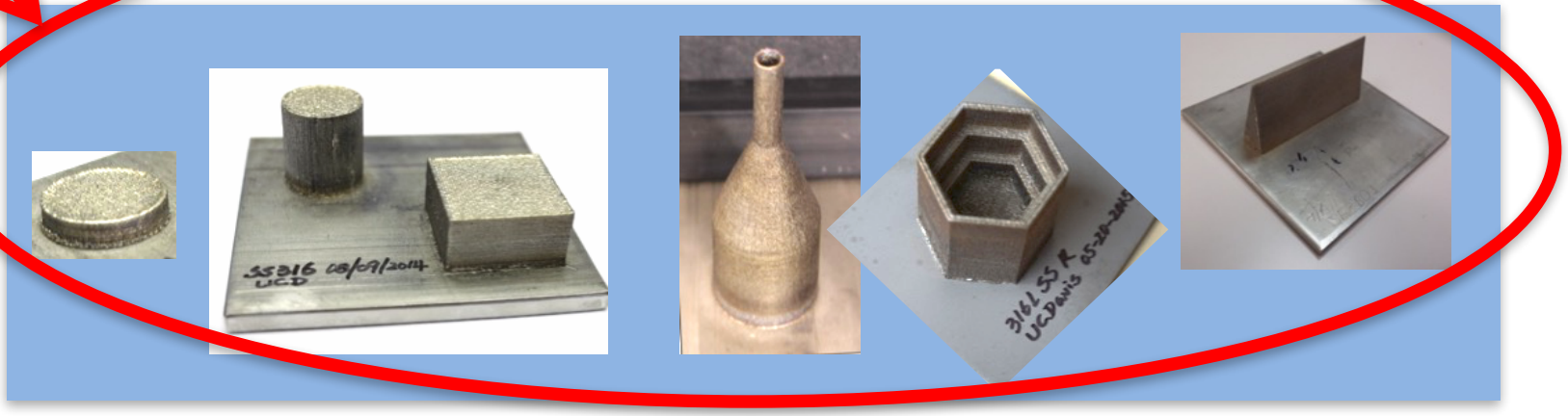
Enable

AM system engineering with ultimate material assurance

SS 316L prototypes printed for R&D & prototyping studies

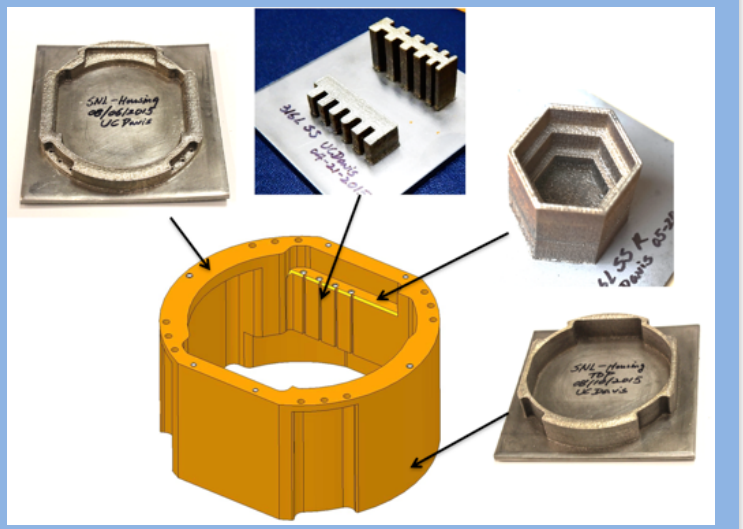
Today's focus

3-D AM material science R&D



3-D AM prototyping feasibilities

3-D LENS

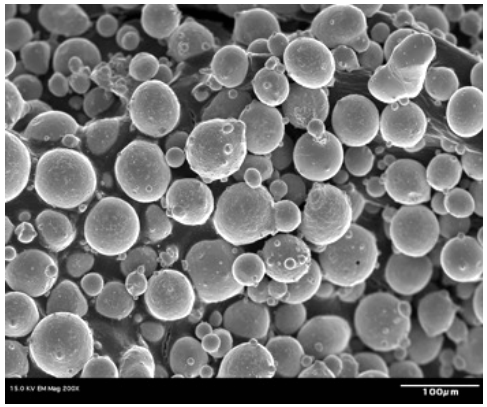


3-D PBF

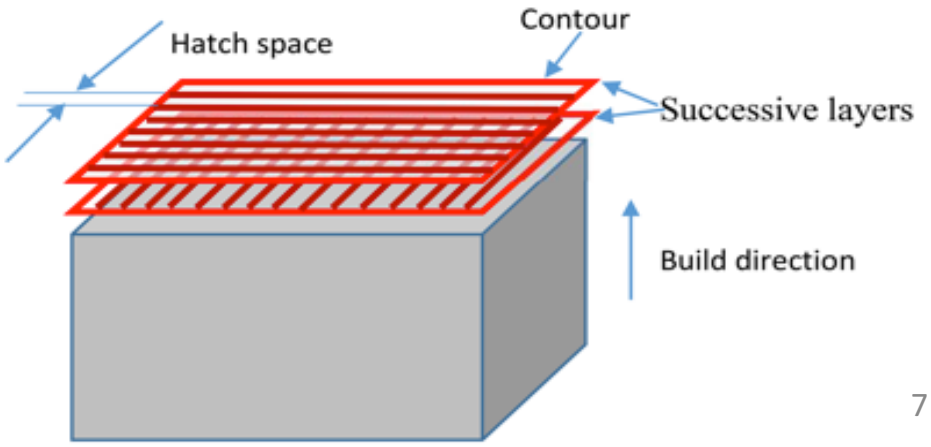
3-D LENS printing parameters and conditions used

Parameters	Setting	Parameters	Setting
Laser power	~360 W	Laser on feed rate	30 in/min
Hatch space	0.016 in	Laser off feed rate	90 in/min
Hatch angel	90^{o}	Contour feed rate	50 in/min
Hatch shrink	0.005 in	Contour number	1
Layer thickness	0.010 in	Contour offset	--
Acceleration	6000 in/min^{2}	Powder feed rate	3

Gas-atomized SS 316L powders, 50µm -150µm in size

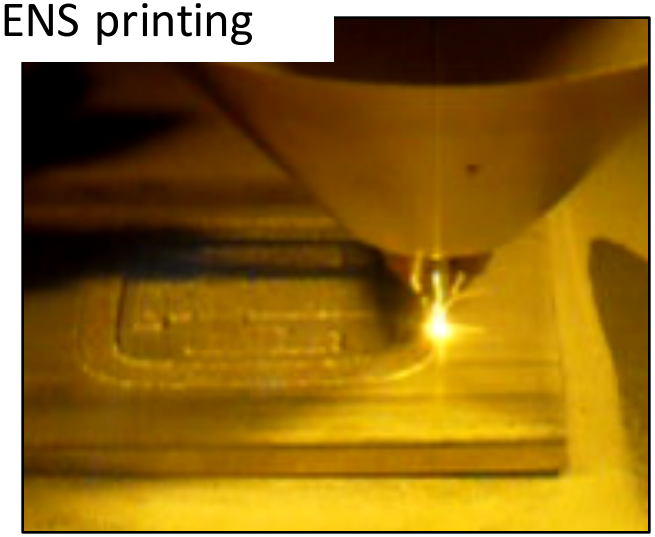


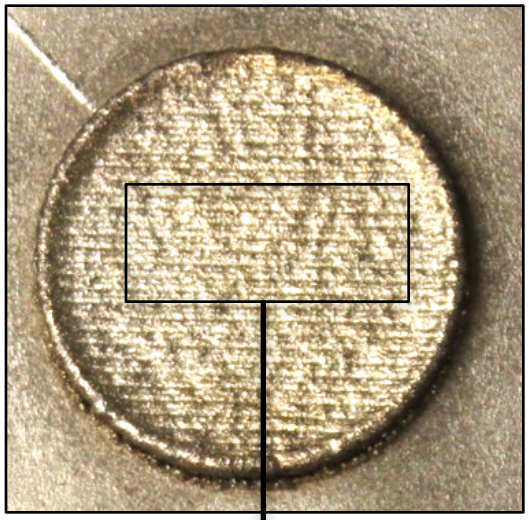
Metal building hatch pattern

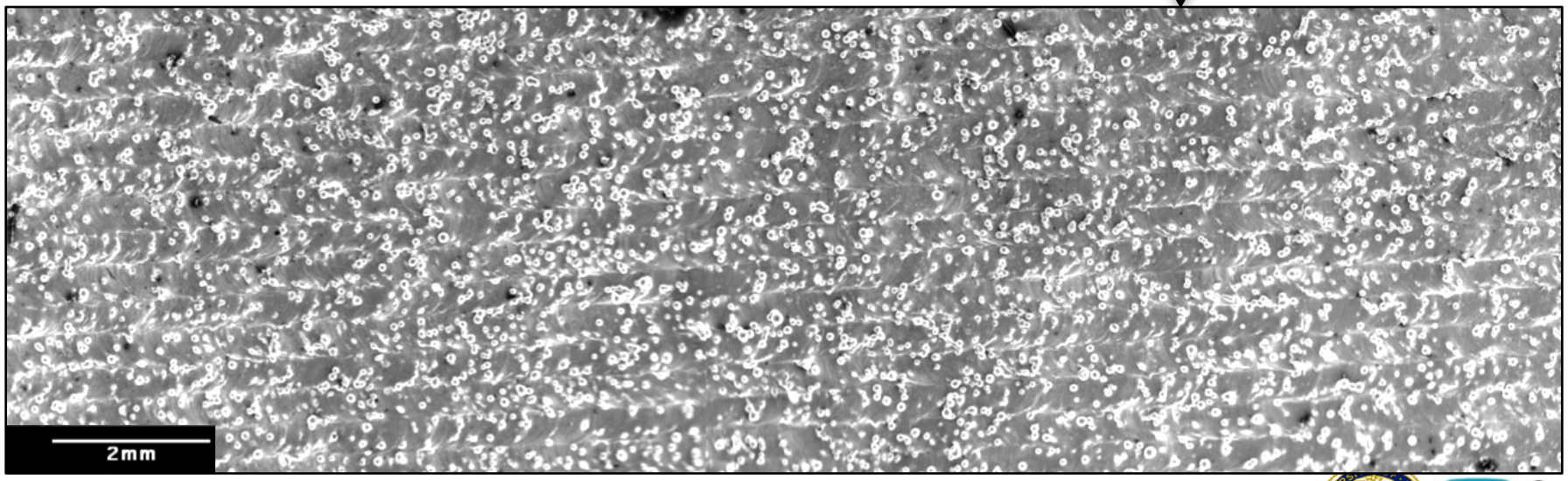


Modulated interpass and flying feedstock powder deposition commonly observed on 3-D LENS print surfaces

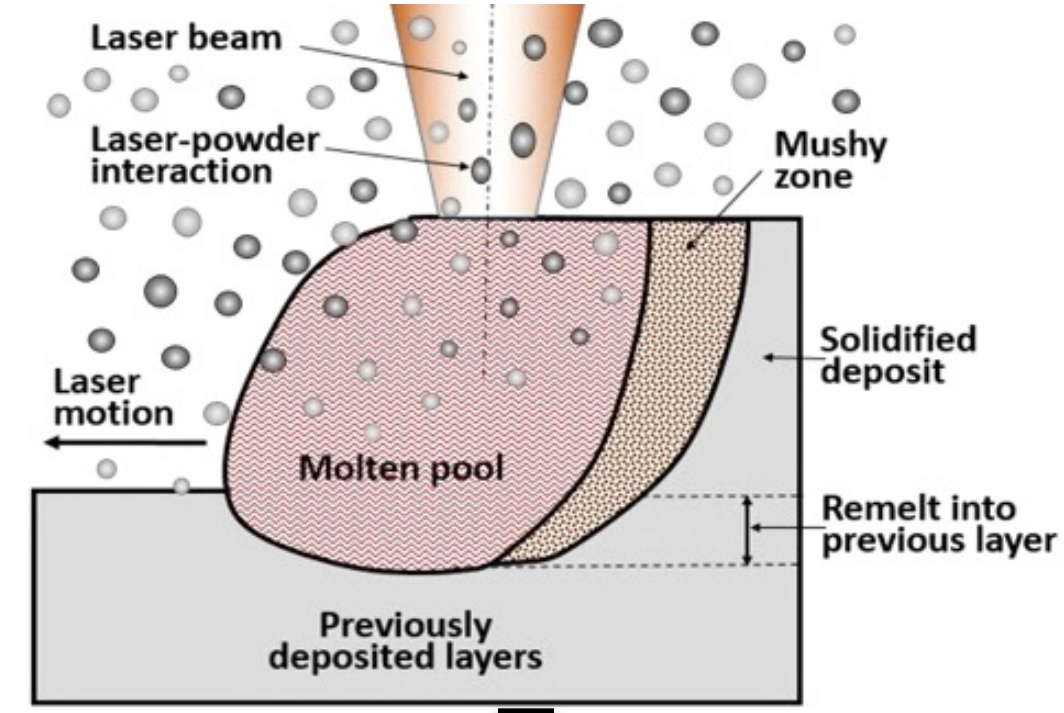
3-D LENS printing

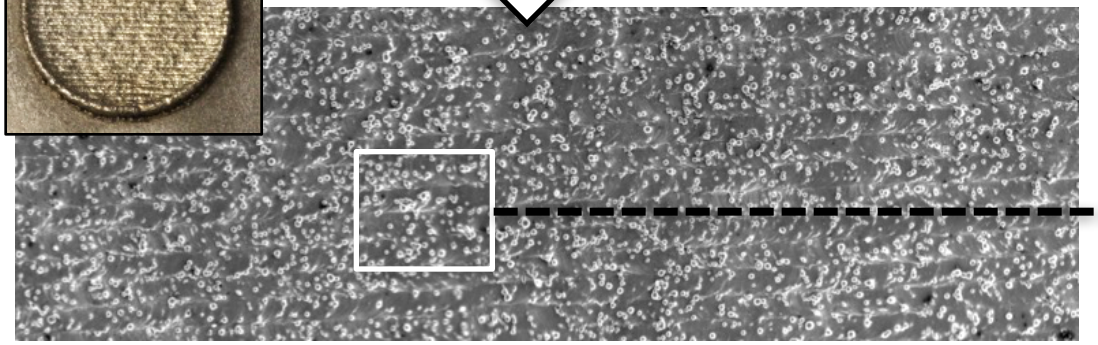


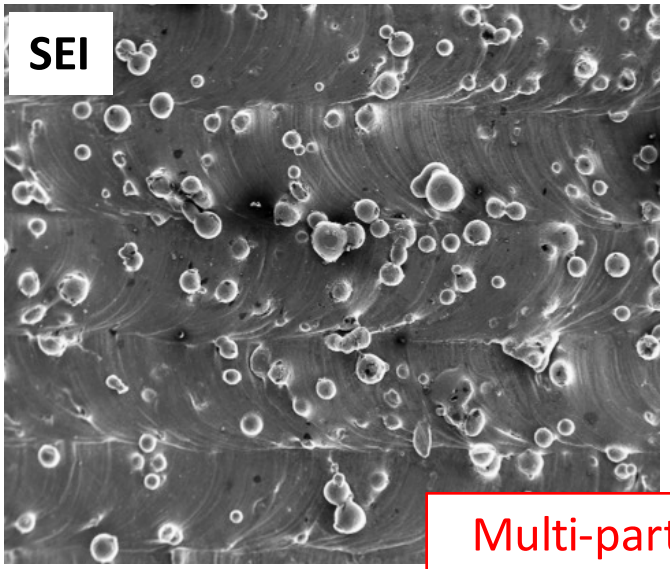




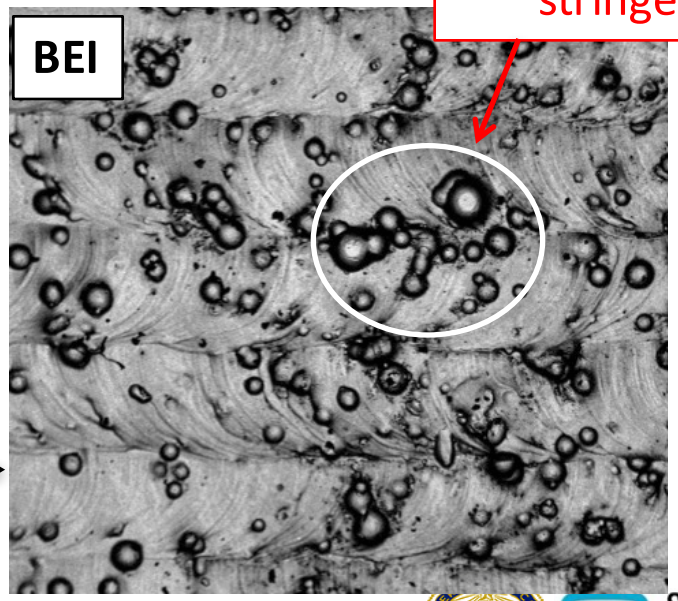
The flying feedstock powders fused on free surfaces, top & sidewall, along interpasses or metal flow trails







Multi-particle stringer



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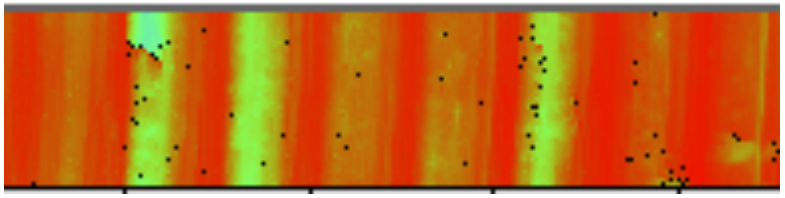
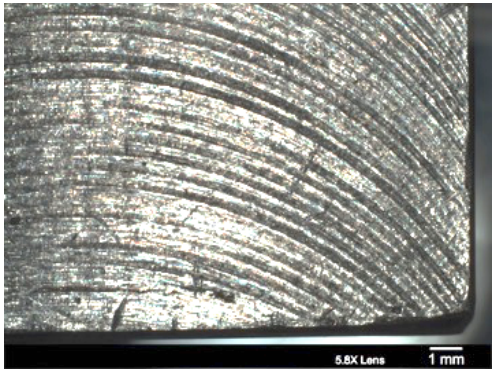
Surface finish of LENS prototype is less uniform and rougher relative to those by mechanically machining

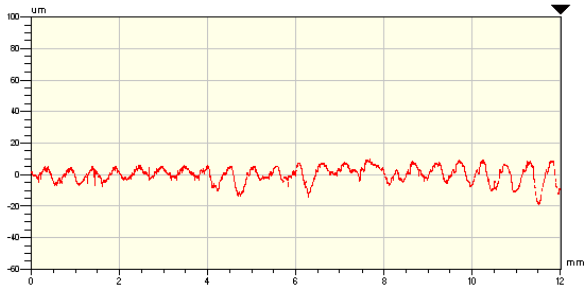
Mechanically machined



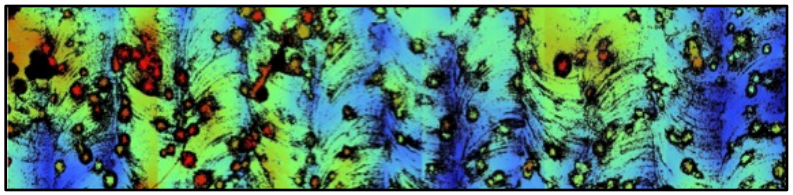
Rz: 37.60 um (Average)

Rt: 58.54 um (Peak –valley)





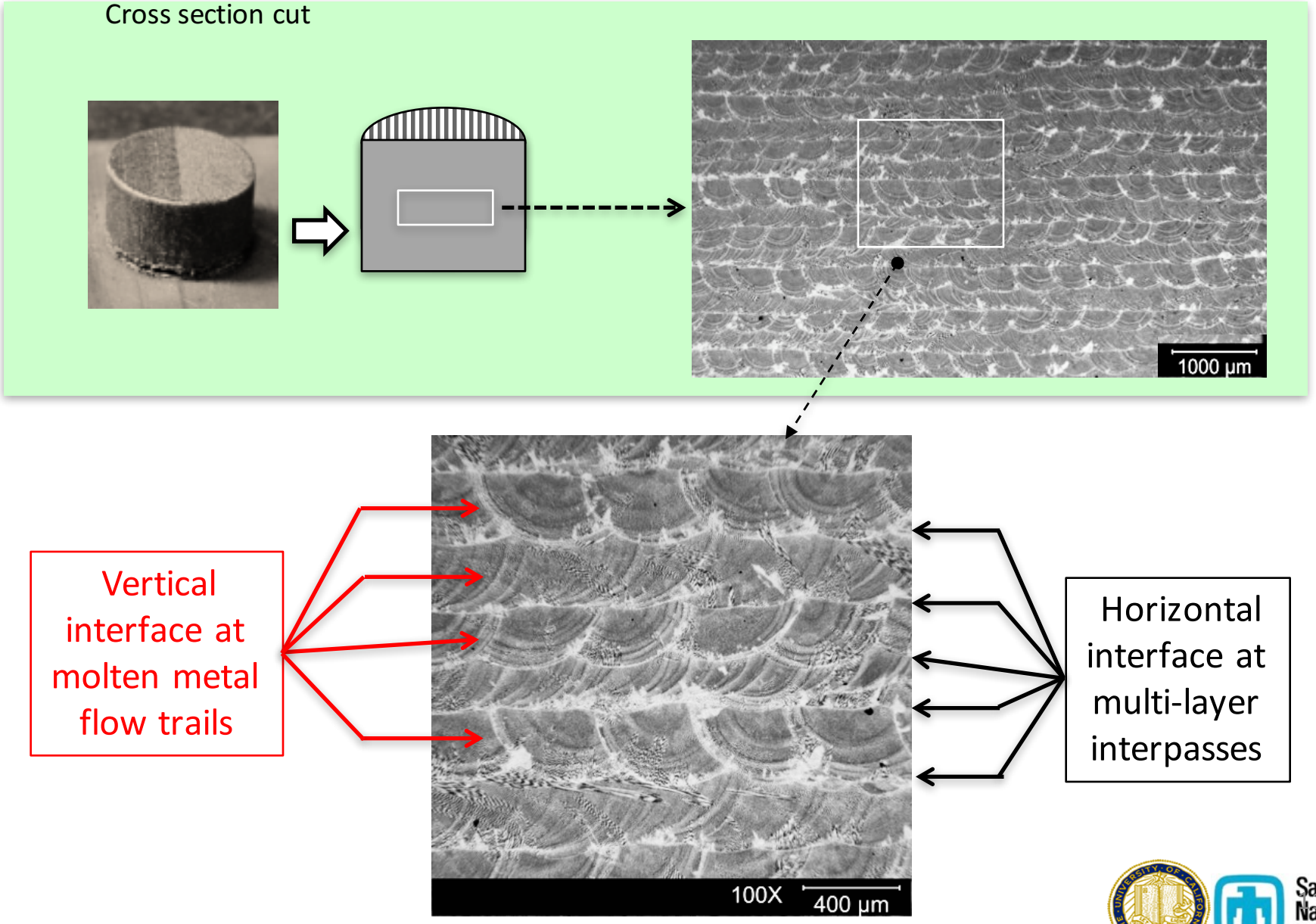
3-D LENS printed



Rz: 326.24 um (Average)

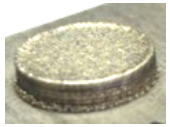
Rt: 418.07 um (Peak –valley)

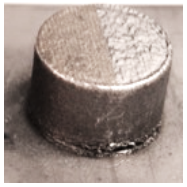
Chemical etching reveals mesh-like landscape outlining the molten metal fusion interfaces of the SS 316L prototypes

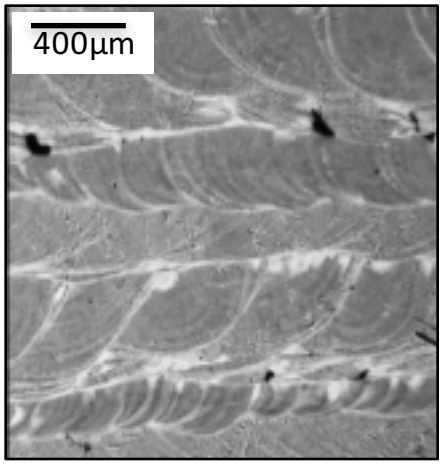


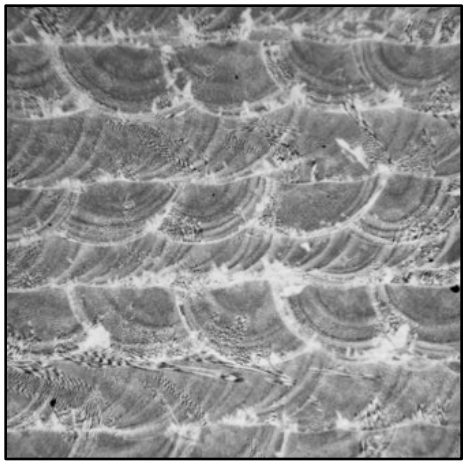
The molten metal fusion induced landscape varies with print geometry & dimension depending on hatch pattern

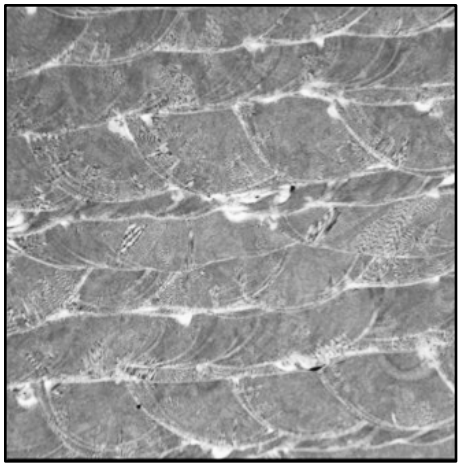
Thin disc:	Bulk cylinder	3-tier hexagon	Thin wall funnel
~ 4mm thick	~25mm thick	Varying width	~1mm wide

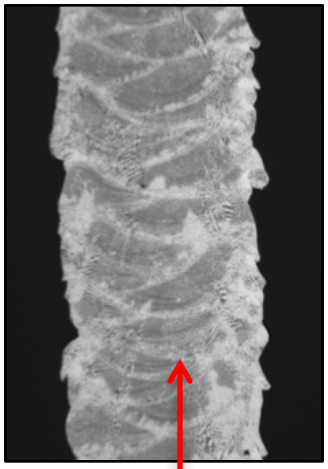










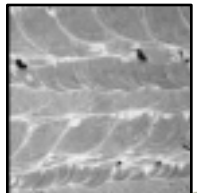


3-D built direction

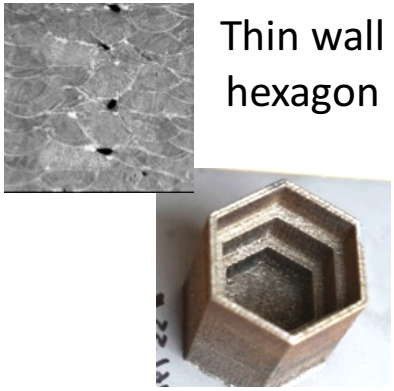
Ill-defined interpass

3-D LENS-induced solidification cell morphology also varied with geometry depending on hatch pattern and local thermal transport

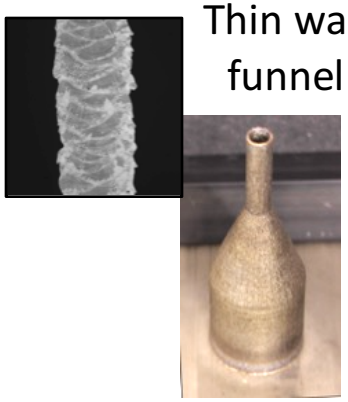
Thick wall disc



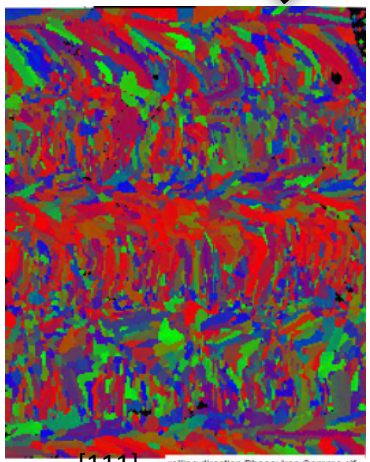
Thin wall hexagon

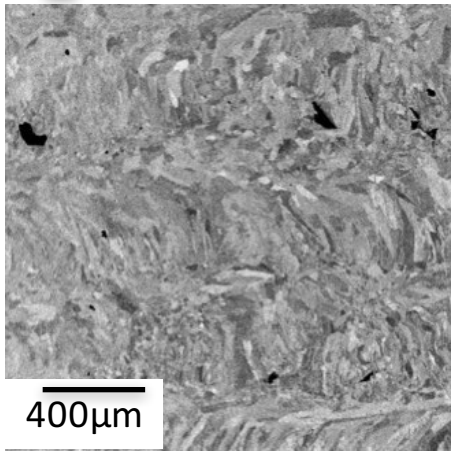


Thin wall funnel

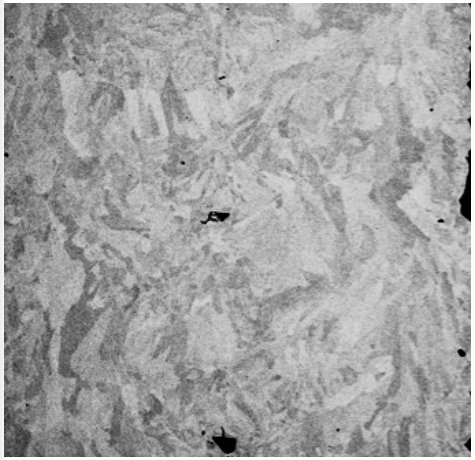


EBSP show moderate preferred orientation for each pass

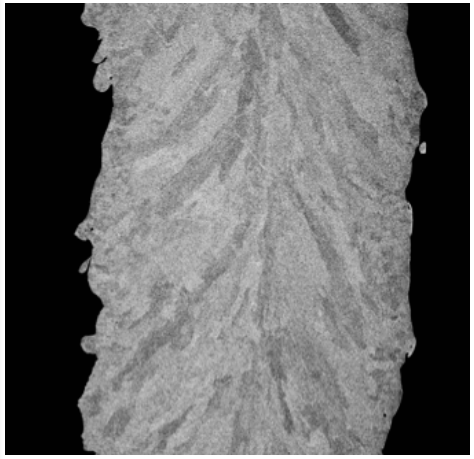




- High aspect ratio fine cells with moderate preferred orientation
- Interpass confines Cell growth



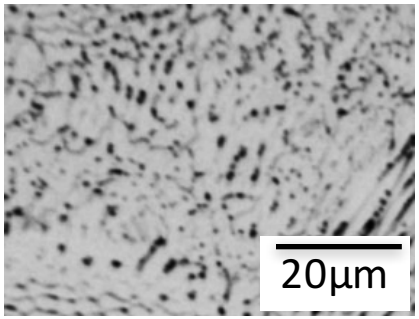
- High aspect ratio coarse cells
- Cell grows randomly



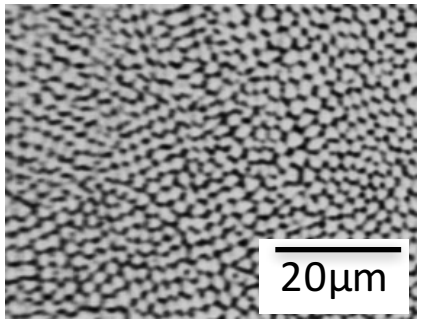
- High aspect ratio coarse cell
- Bimodal cell growth toward sidewall

Mesh-like landscape contains interpass HAZ, well-fused metal flow trails, and extremely fine solidification cell structure (<5µm)

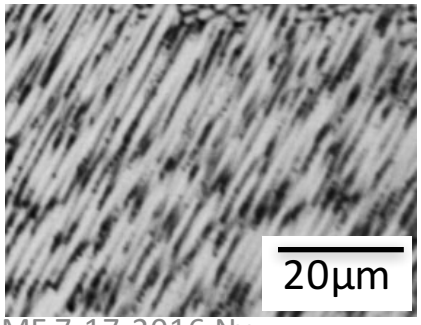
1. Ill-define mushy zone



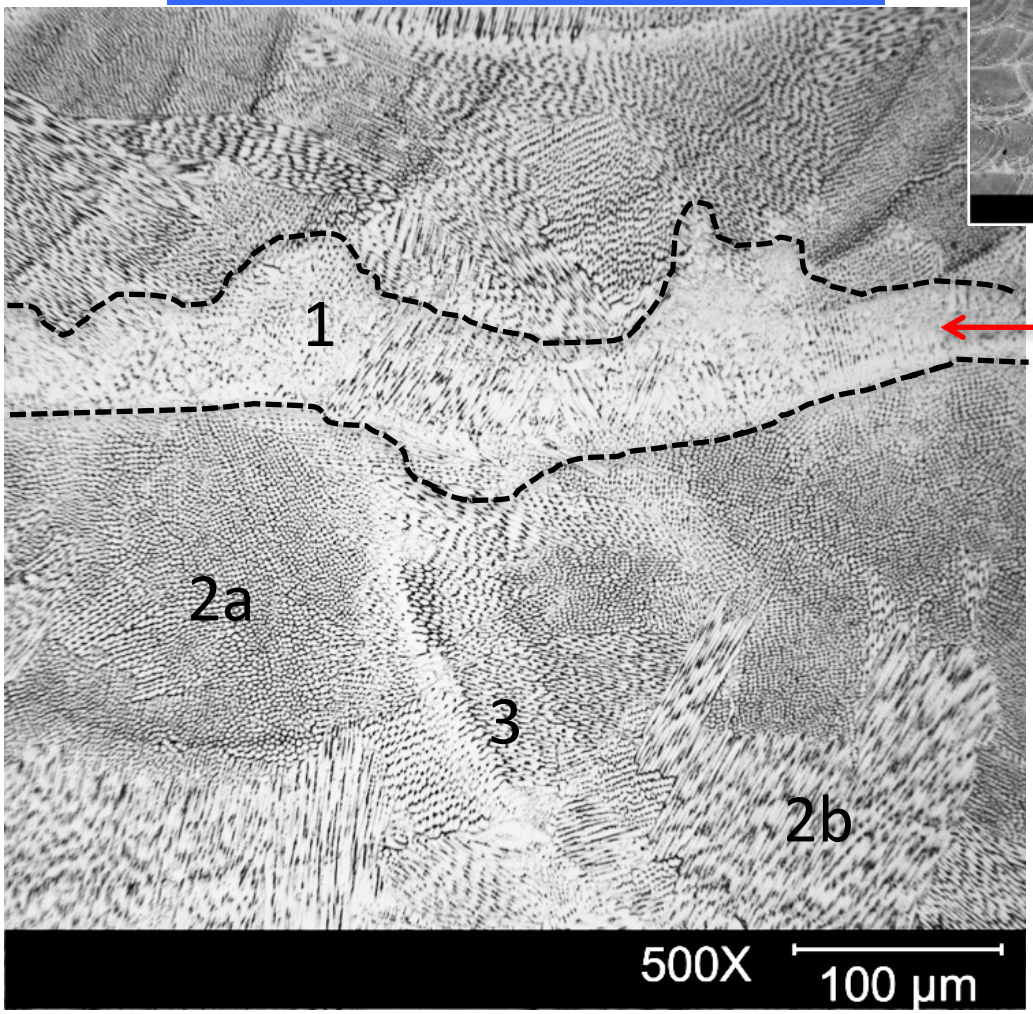
2a. Solidified cell-Trans.

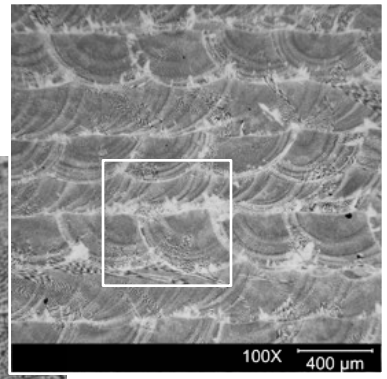


2b. Solidified cell-Long.



Microstructural features in the mesh-like landscape

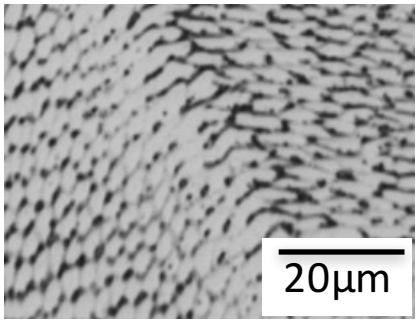




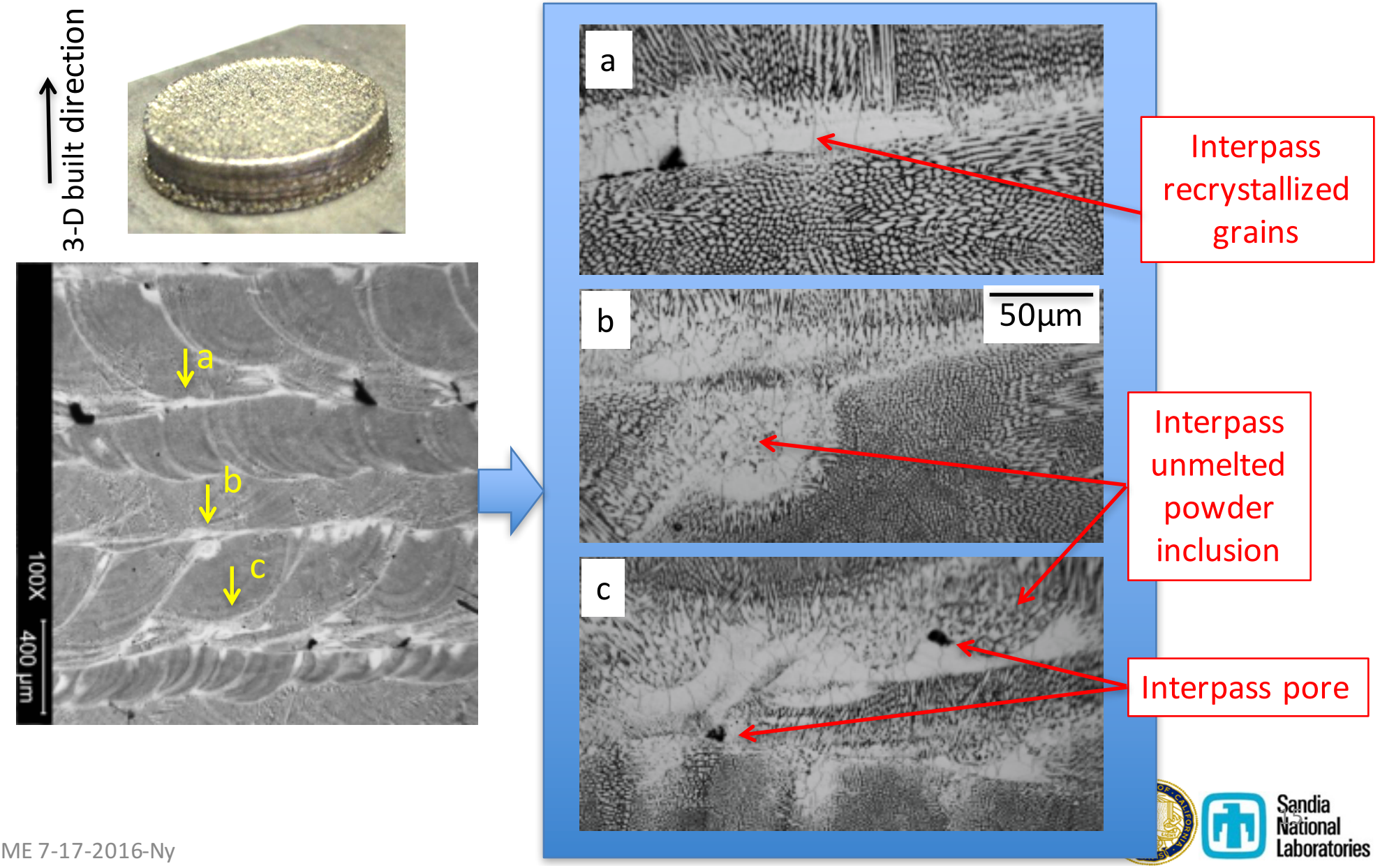
3-D built direction

Interpass heat affected zone (HAZ) induced by reheating/remelting

3. Interface at metal flow trail

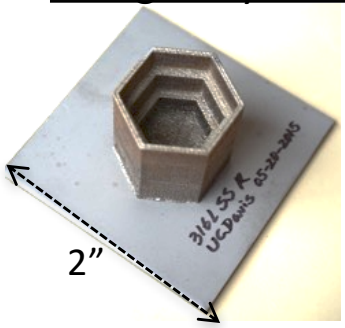


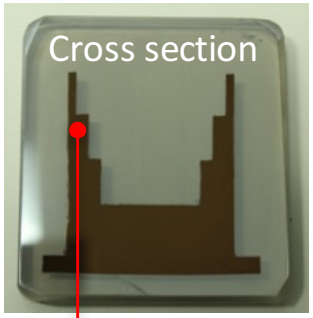
Unmelted powder inclusion, pore, and coarse recrystallized grain may be part of HAZ depending on local thermal condition

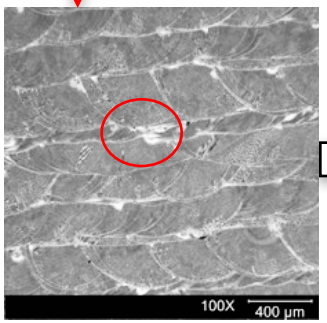


HAZ with unmelted powders inclusions, pores and coarse recrystallized grains also observed in the 3-tier hexagon

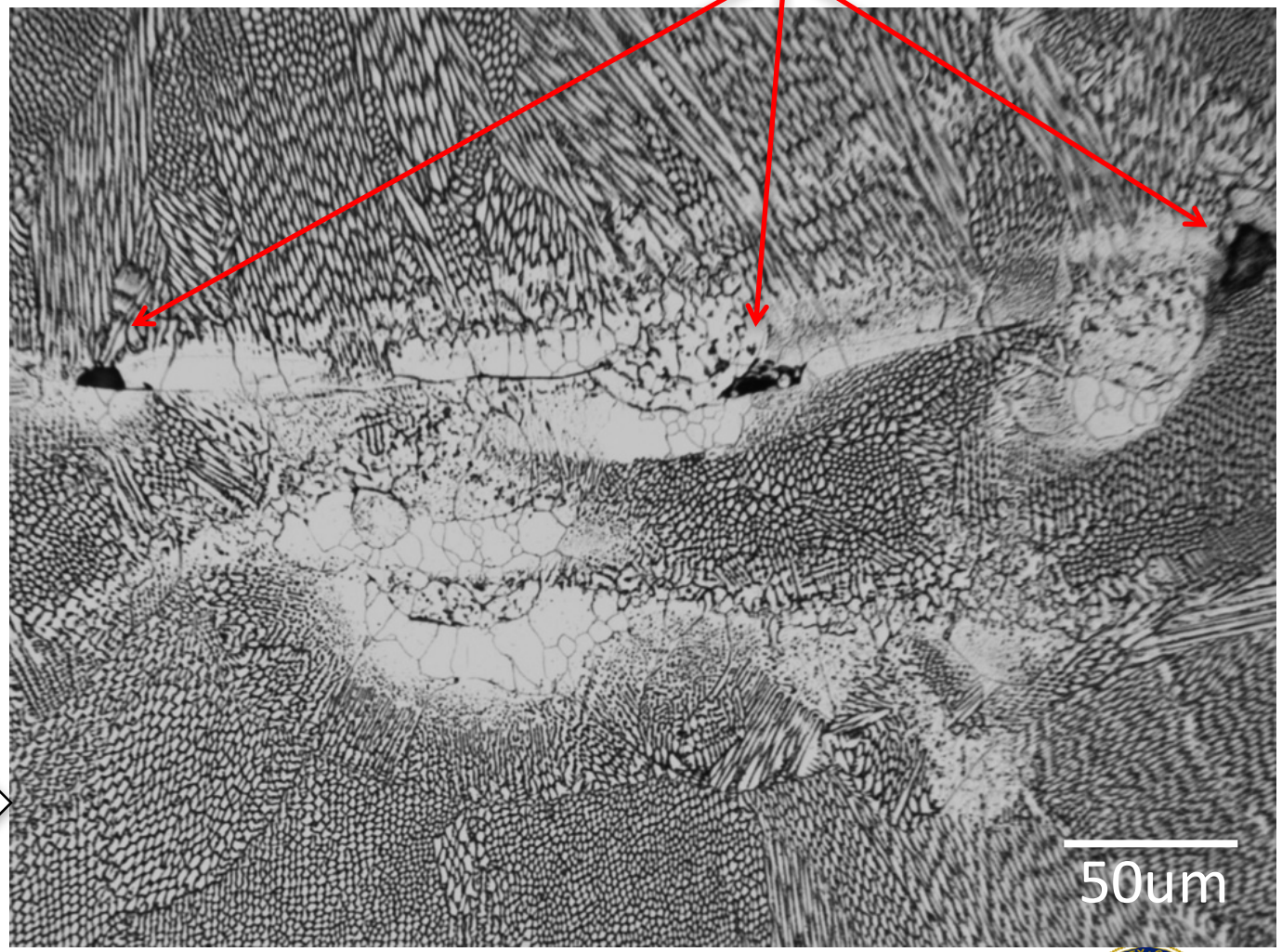
3-D LENS printed hexagon by UCD



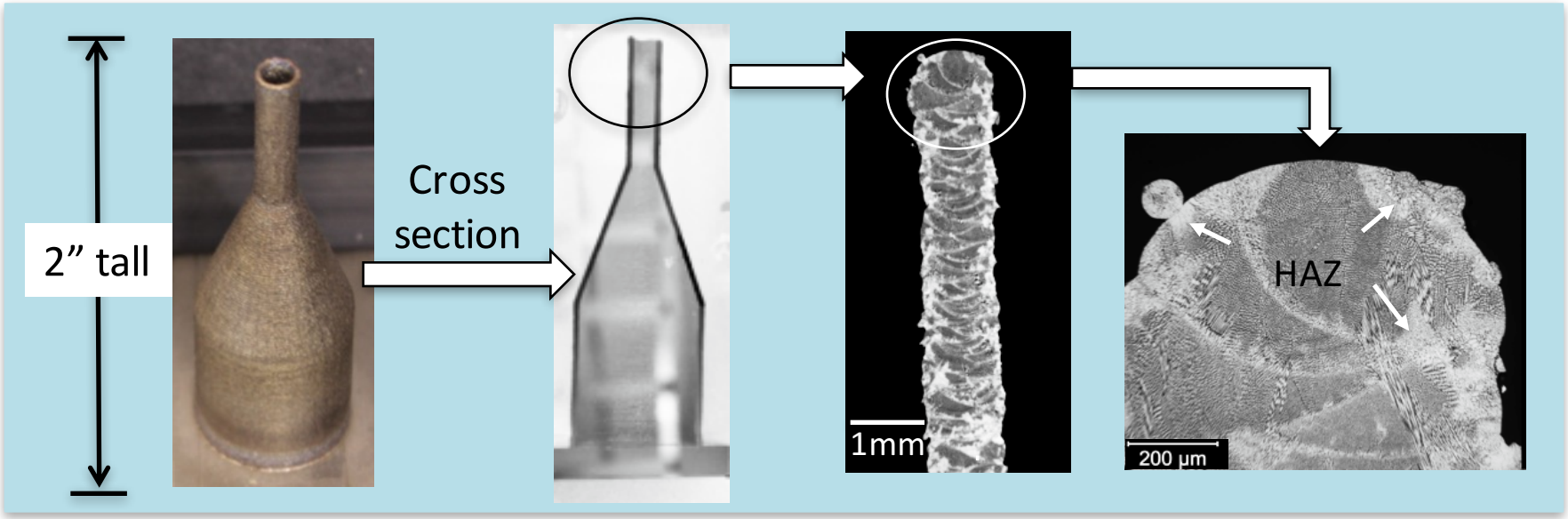




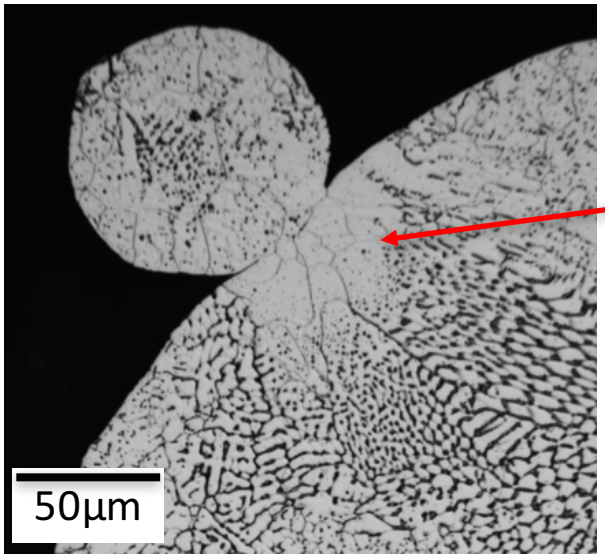
Interpass porosity

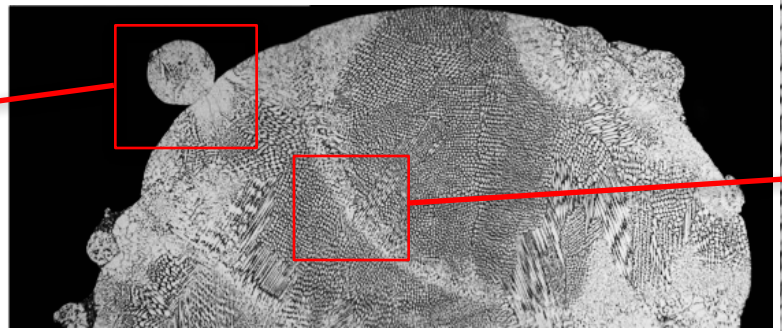


HAZ with coarse recrystallized grains commonly observed beneath the fused-on flying powders on the thin wall funnel

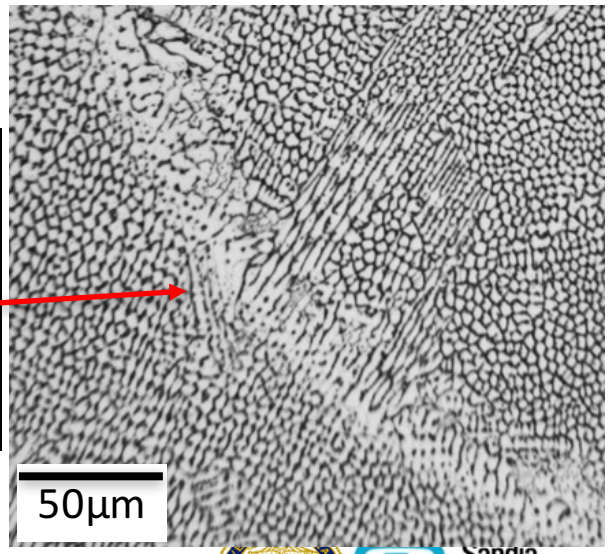


Recrystallized grain

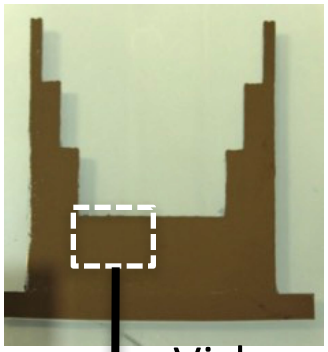




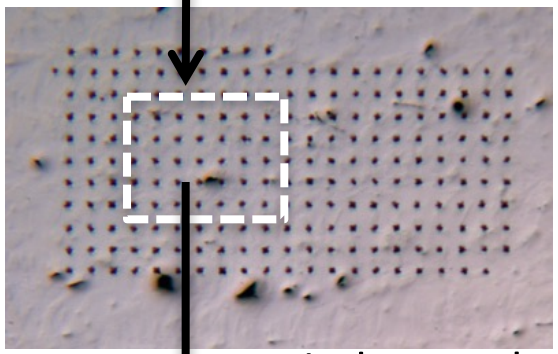
Epitaxial fusion interface



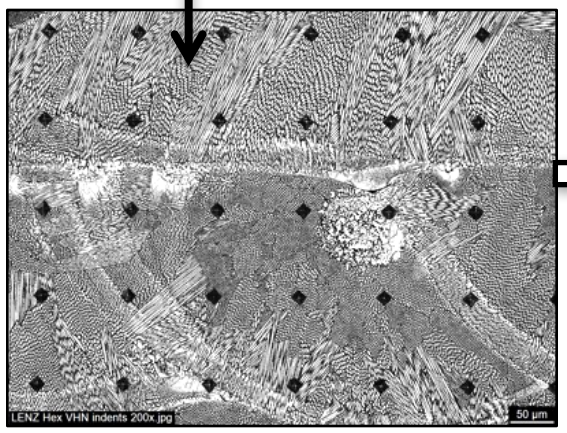
3-D LENS hexagon exhibits greater harder but less uniform Vickers microhardness solidification structure



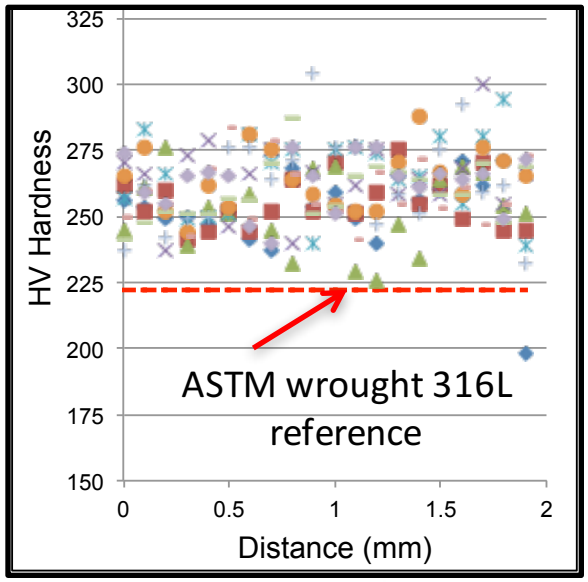
Vickers Indents



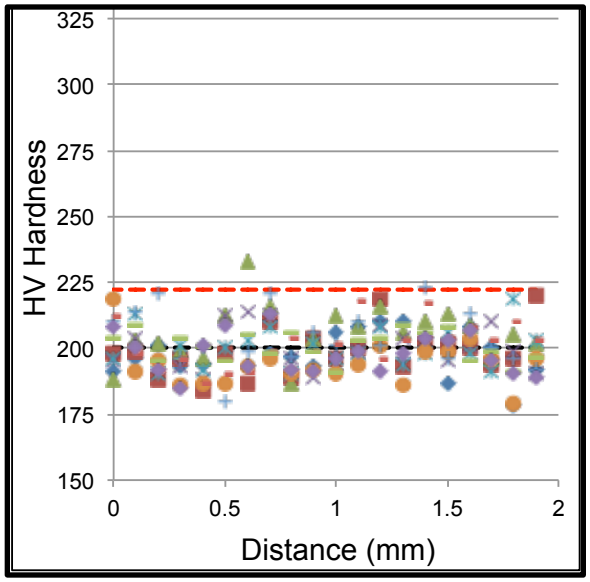
Post indent etch

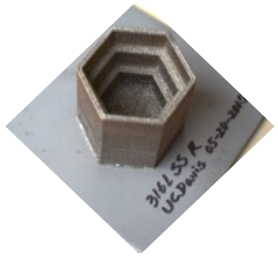


LENS hexagon (STDEV~15)



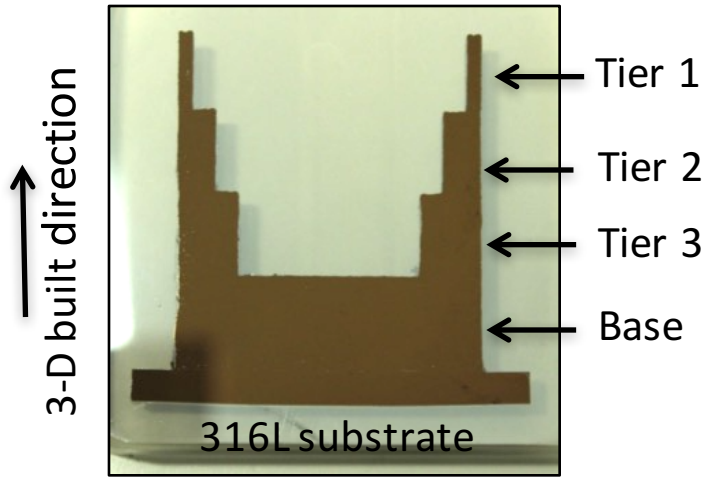
Wrought 304L (STDEV~9)

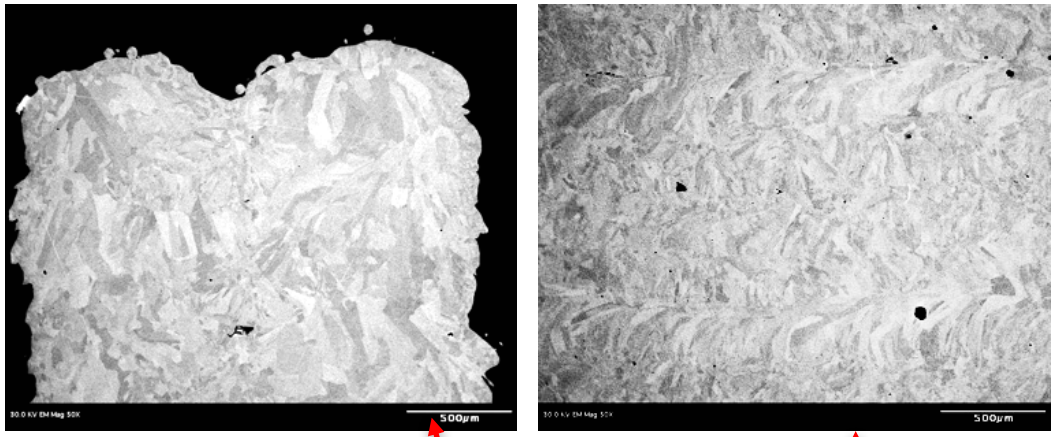


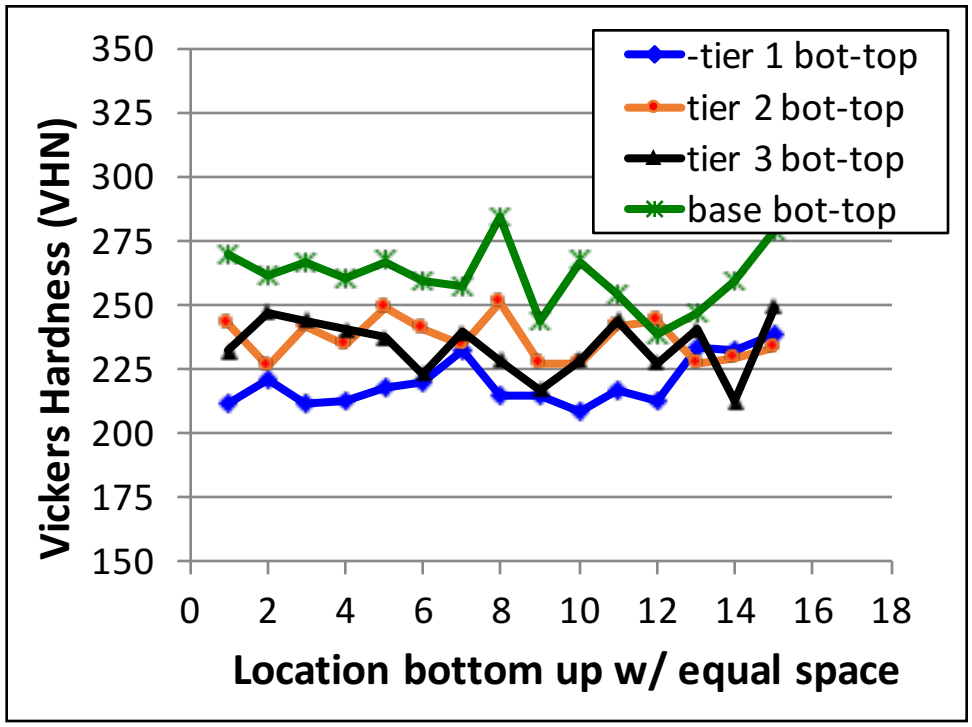


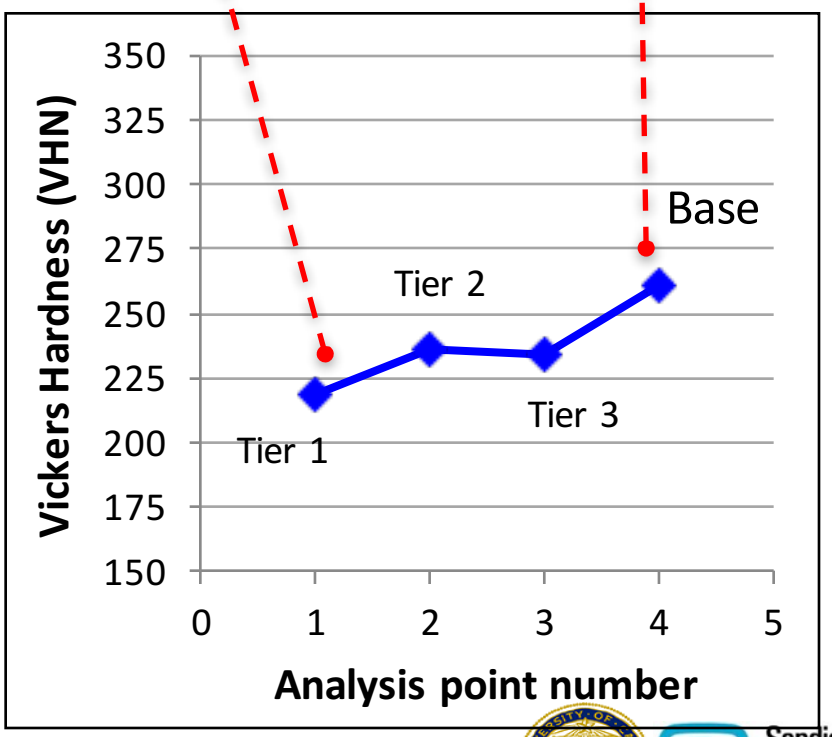
Harder and less uniform in Vickers microhardness attributed to the fine solidification cell structure and presence of the systematic interpass HAZ.

Systematic decrease in hardness with distance from the substrate & part thinning attributed to cell coarsening ?



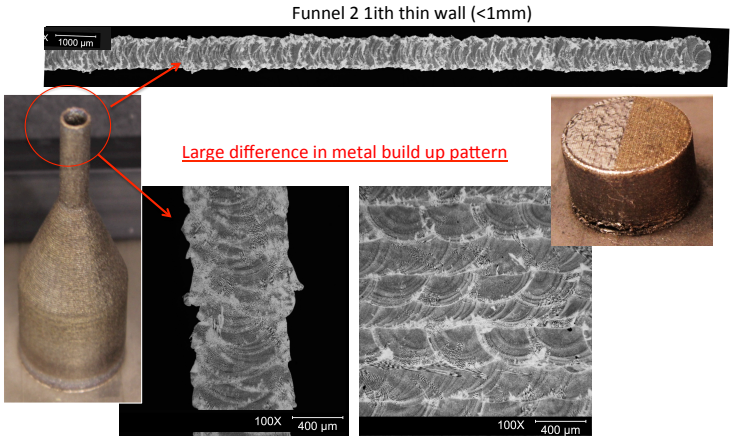






Summary

- The metallurgical characteristics of the 3-D LENS SS 316L is print geometry/size/location dependent due to localized heat transport and distribution.
- The systematic mesh-like HAZ, impacts the engineering property and behavior, and possibly local environmental response to corrosion.
- The metallurgical evolution within the HAZ must be understood and controlled in order to achieve a ultimate material assurance.
- Innovated 3-D LENS process optimization strategy, coupled with model simulation/ validation, is the key to control the physical metallurgy for building a reliable & robust engineering system.



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