SAND2015-3800C

Metallurgical evolution during laser additive manufacturing of metal and composite alloys

Nancy Y. C. Yang[1], Kyle Gaiser[1], Lee Clemon[1], and Chris San Marchi[1]
Baolong Zheng[2], Yizhang Zhou[2], Enrique J. Lavernia[2] and Julie M. Schoenung[2]

[1] Sandia National Laboratories, Livermore, CA 94551-0969

[2] Department of Chemical Engineering and Materials Science
University of California at Davis, Davis, CA 95616

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

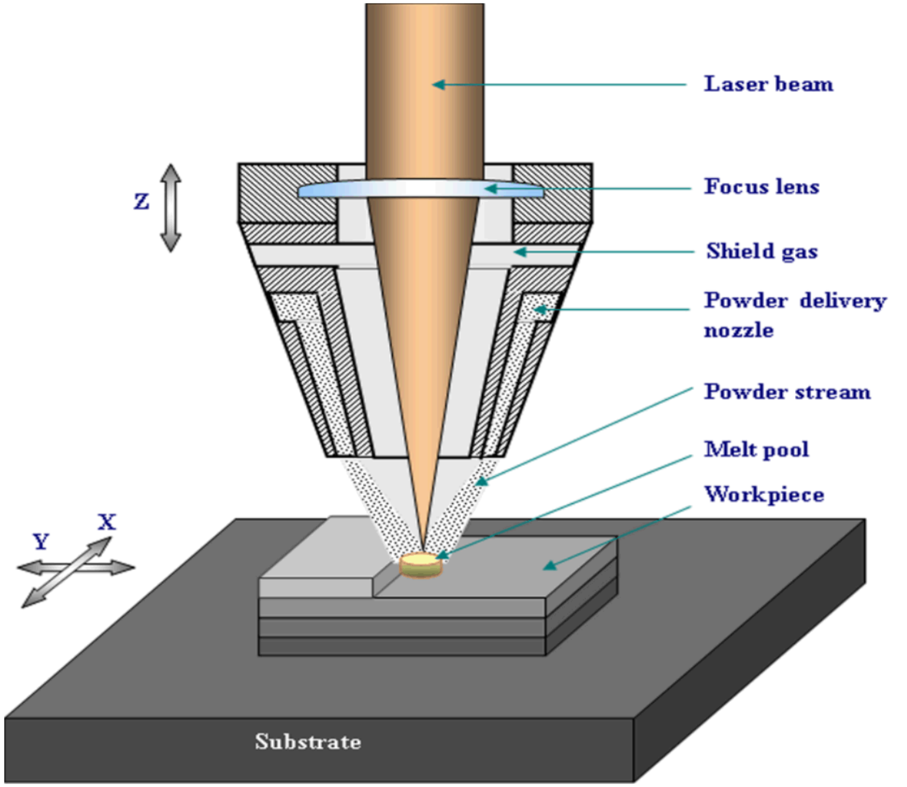
Outline

- Introduction
- Programmatic goal (UC Davis/SNL,CA collaboration)
- Technical undertakings
- 3-D LENS prototype printing and metallurgy for 316L stainless steel
- Summary

Introduction

What is laser additive manufacturing (AM)?

- Additive manufacturing (AM), Direct Energy Deposition (DED) and Powder Bed Fusion method, are effective for printing 3-D components with complex shapes and dimensions.
- AM is a thermally driven powder consolidation process that involves simultaneous powder heating/melting, molten alloy flow, and solidification.

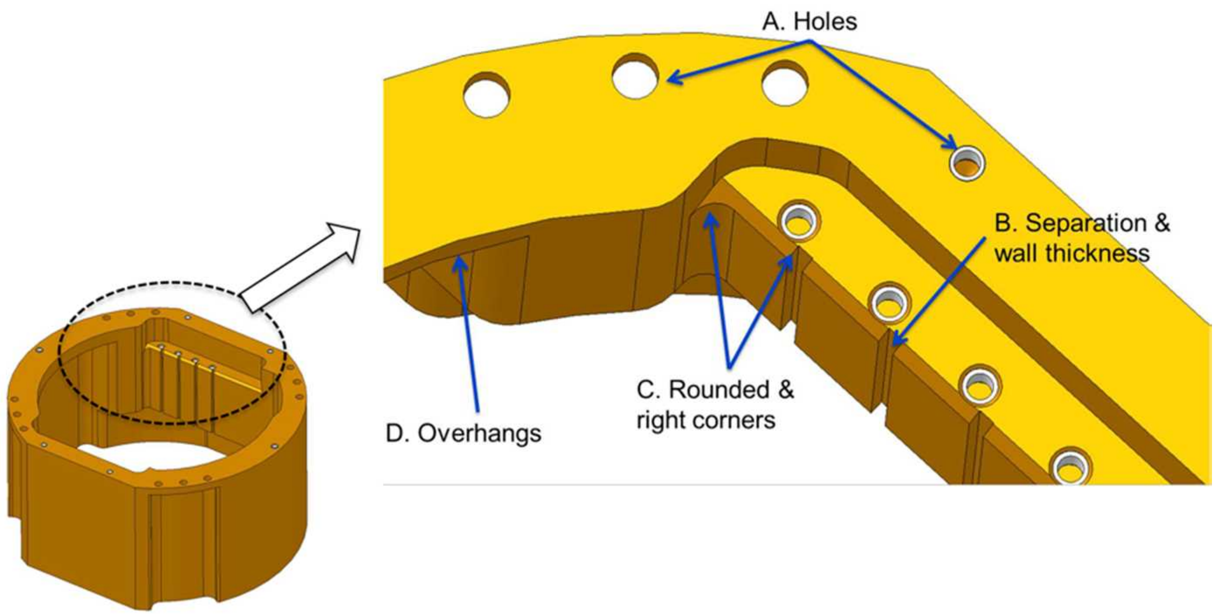


Courtesy of Baolong, UCD

Programmatic goal

(UC Davis/SNL,CA collaboration)

- Understand the process-structure-property relationship that enables control of the physical metallurgy.
- Develop/mature 3-D DED printing technology for prototyping deployed parts with complex shapes and dimensions.



National Nuclear Security Administration

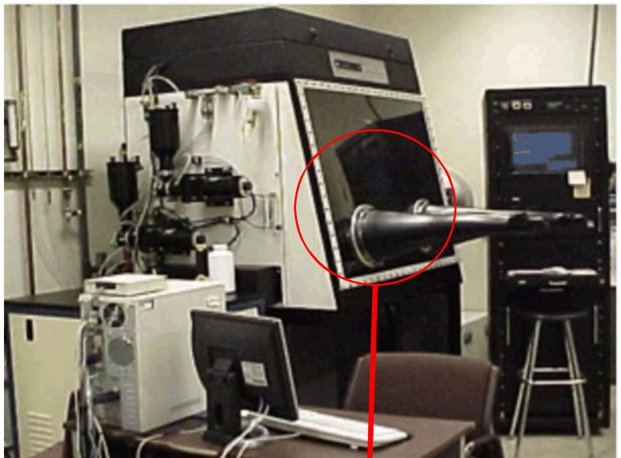
Sandia National Laboratories

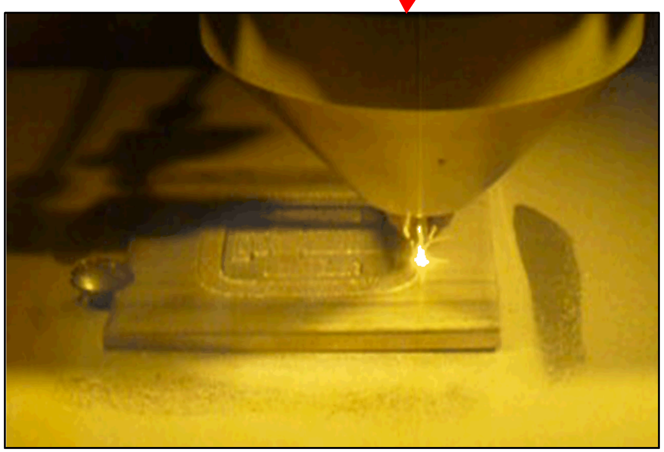
Technical undertakings

- Al/Al_3Ni composite foam
- WC+Co cermet wear resistant composite
- Material science and prototyping of 316L stainless steel

Today's focus

Laser-Engineered Net Shaping (LENS) System at UC Davis





LENS workstation 750 is equipped with real-time melt pool size sensor (MPS) control and Z-height sensor control (ZHC) close-loop subsystems.

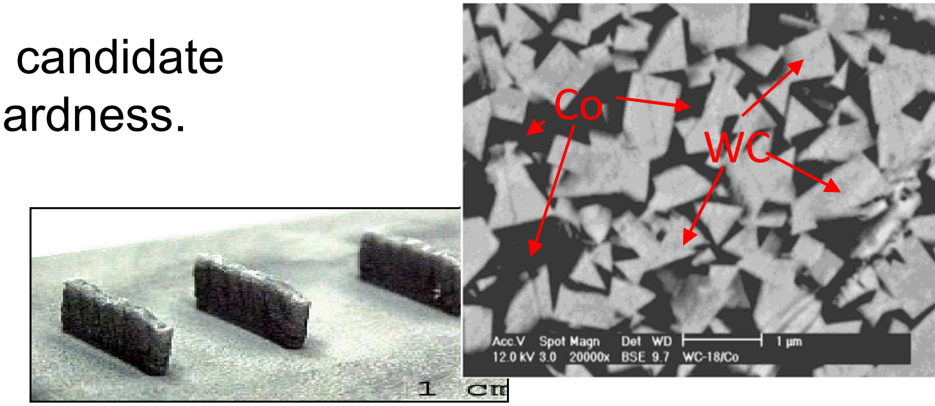
Capability

- 650W CW Nd:YAG laser (1064 nm) to create a melt pool;
- 4-nozzle coaxial powder feed system;
- 3-axis positioning control system assisted by CAD model;
- Controlled environment glove box;
- Energy density in the range of 30,000-100,000 W/cm^2.

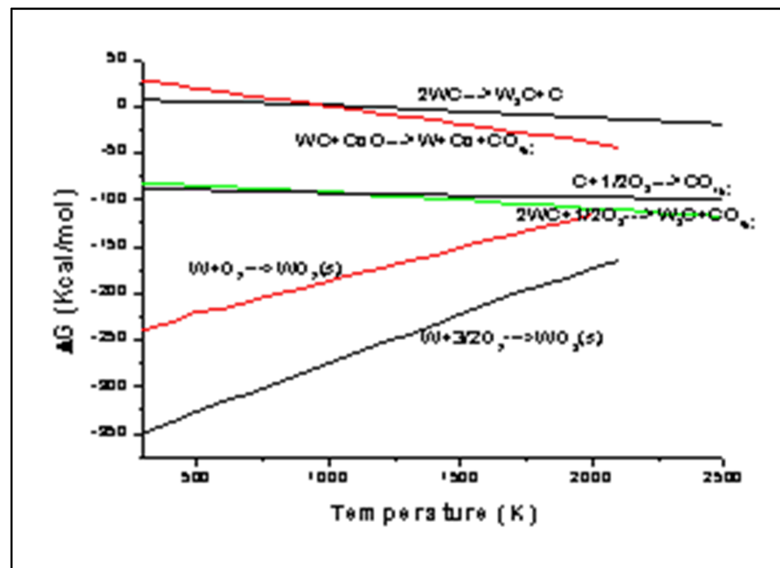
Developing Thermally Stable WC+Co Cermet

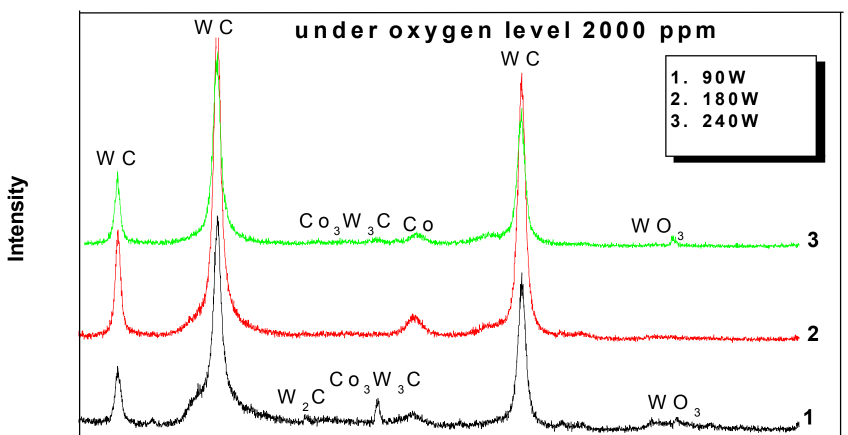
Tungsten carbide (WC) is a well-known candidate for wear resistant for its exceptional hardness.

- Fabricating 3-D LENS parts with WC-Co composites using LENS;
- Understand thermal stability of WC particles during LENS printing;
- Preventing WC decomposition from rapid solidification rate and low oxygen environment during processing.



Possible reactions of W-CO-C system.

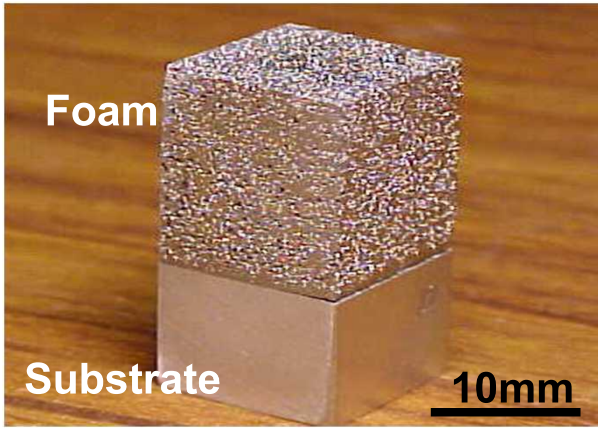


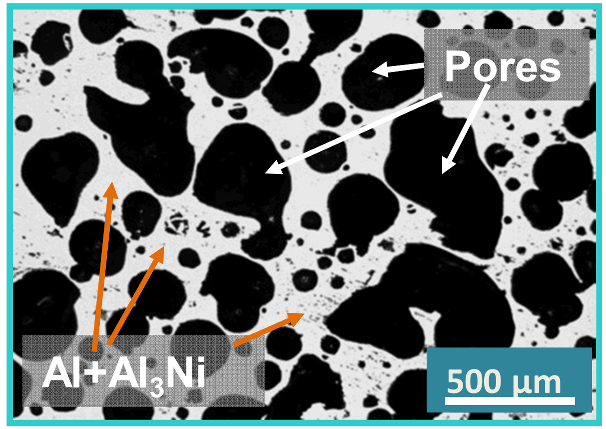


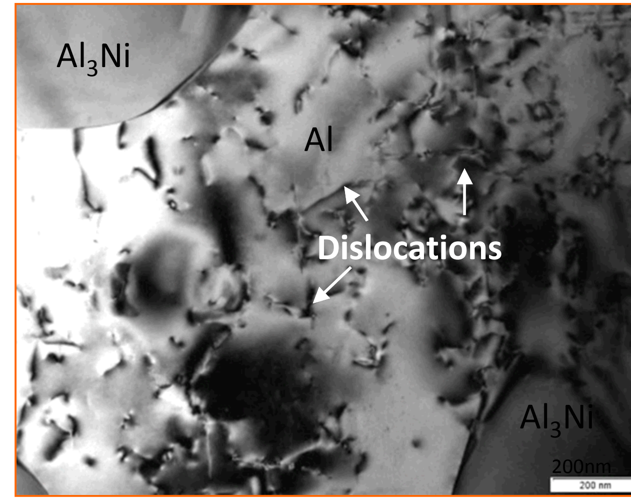
[Xiong, Schoenung, et al., Mater. Sci. and Eng. A, 2008]

Sandia National Laboratories

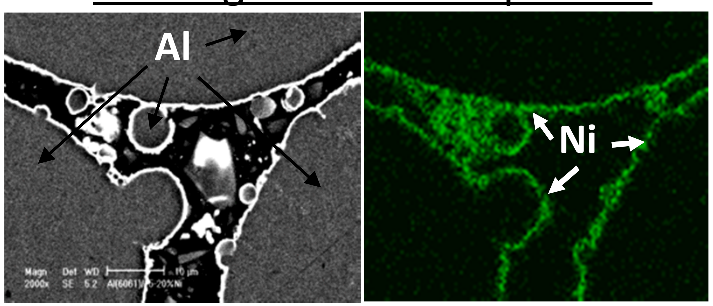
LENS printing for Hybrid Al/Al_3Ni Foams

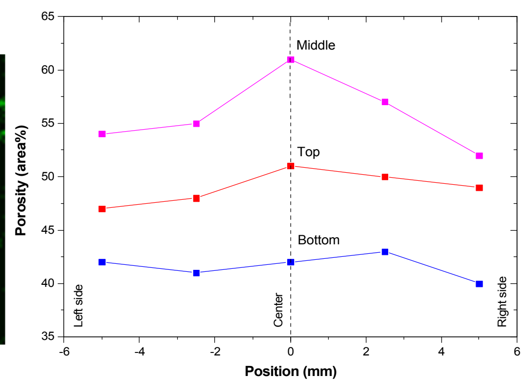


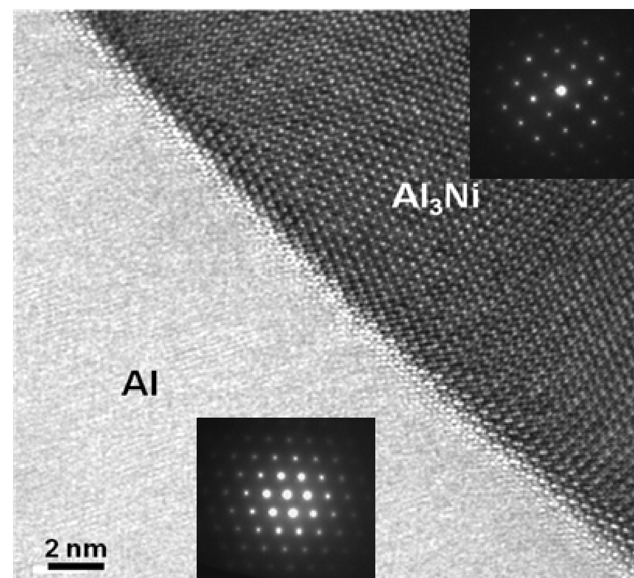




Starting Ni coated Al powder







- The Al/Ni coating reaction yields high porosity, > 60 vol. % and low density, 2.0 g/cm^3.
- The deposited hybrid Al+Al_3Ni foams possess higher strength, attributed to uniformly dispersed Al_3Ni intermetallic in Al matrix,

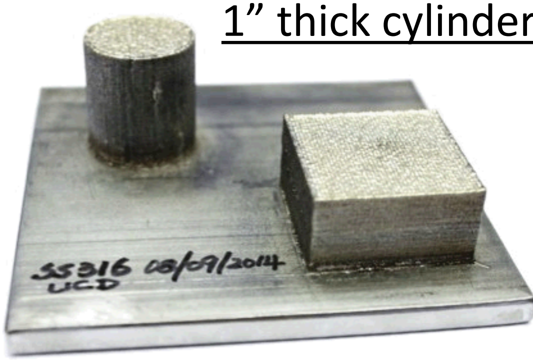
[Zheng, Lavernia, et al., Philosophical Magazine, 2011]

3-D LENS printed 316Lss for material science & metallurgy study

National Nuclear Security Administration

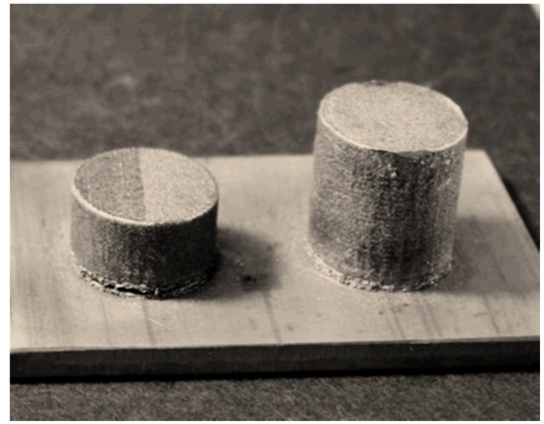
½" thin disc

1" thick cylinder and cube

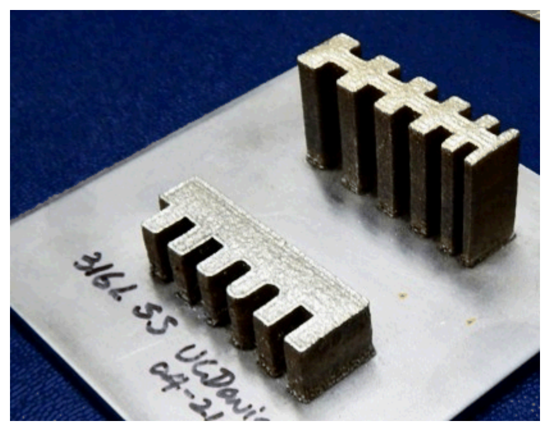


1.5" thin Sandia logo

1" thick cylinders



Print design for testing shape/ dimension limit



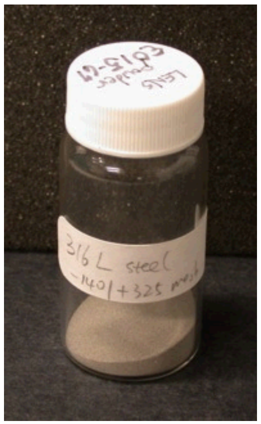
Thin wall funnel

Sandia National Laboratories

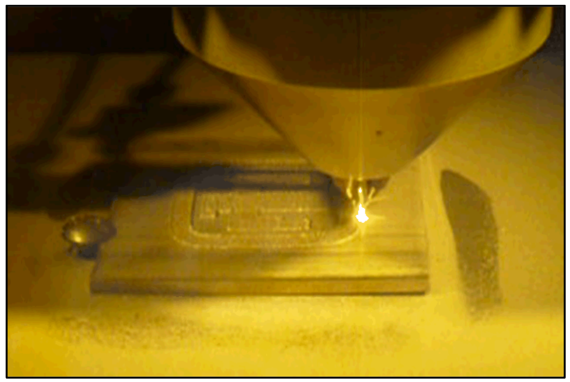
National Nuclear Security Administration

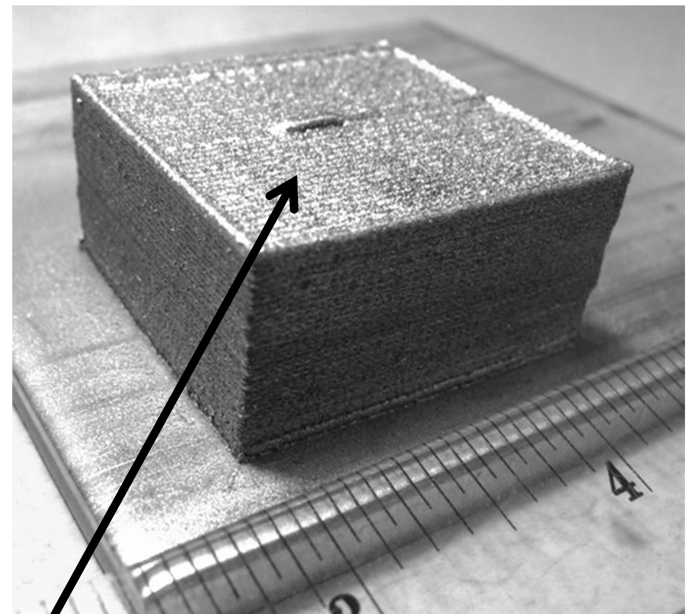
What and how the LENS parameters impact surface topography and physical metallurgy of 316Lss?

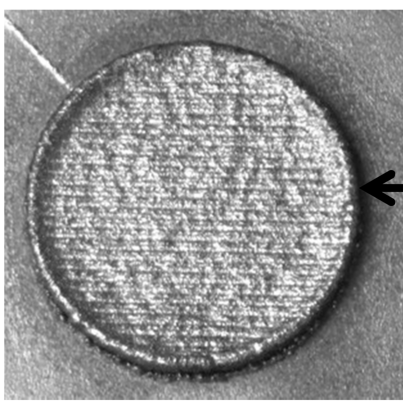
Starting 316L powder

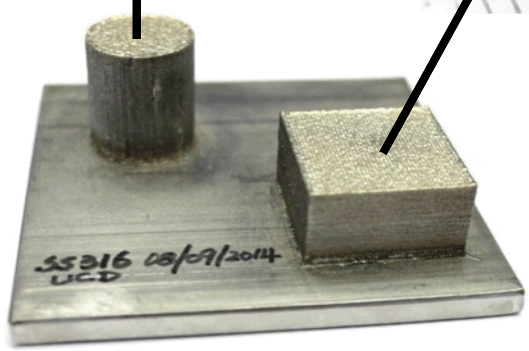


3-D LENS printer



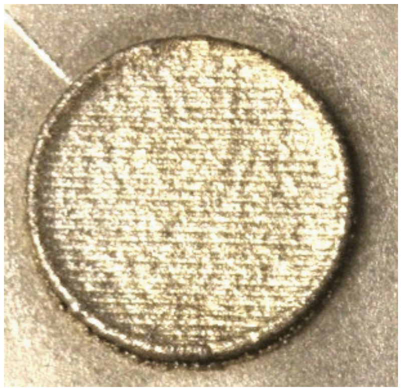


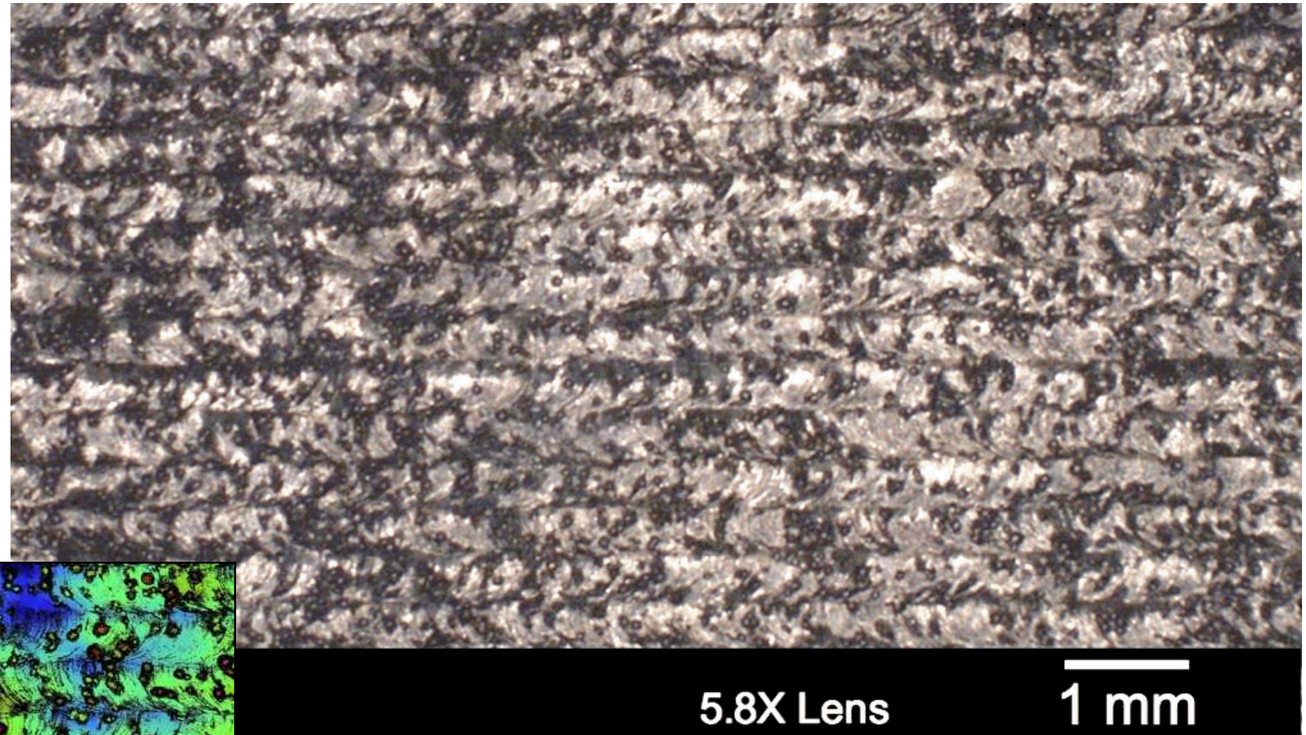


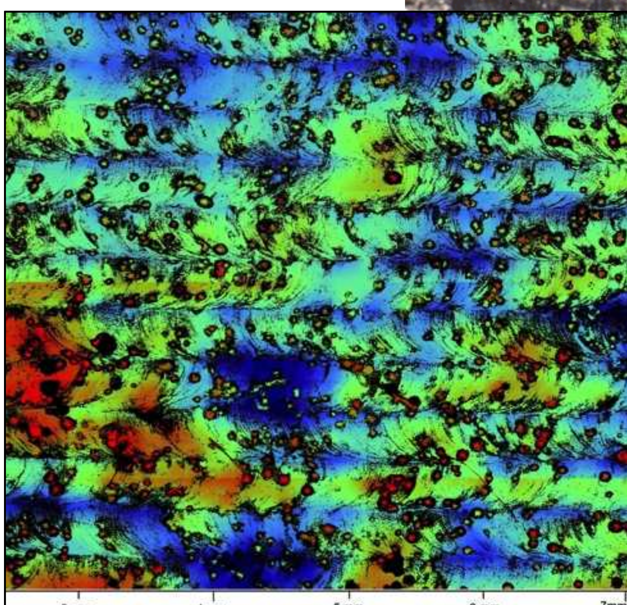


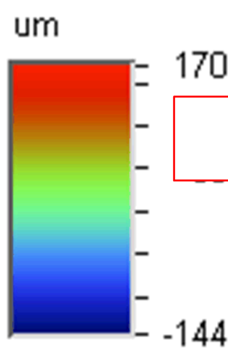
Sandia National Laboratories

Modulated surface morphology induced from multiple laser passes



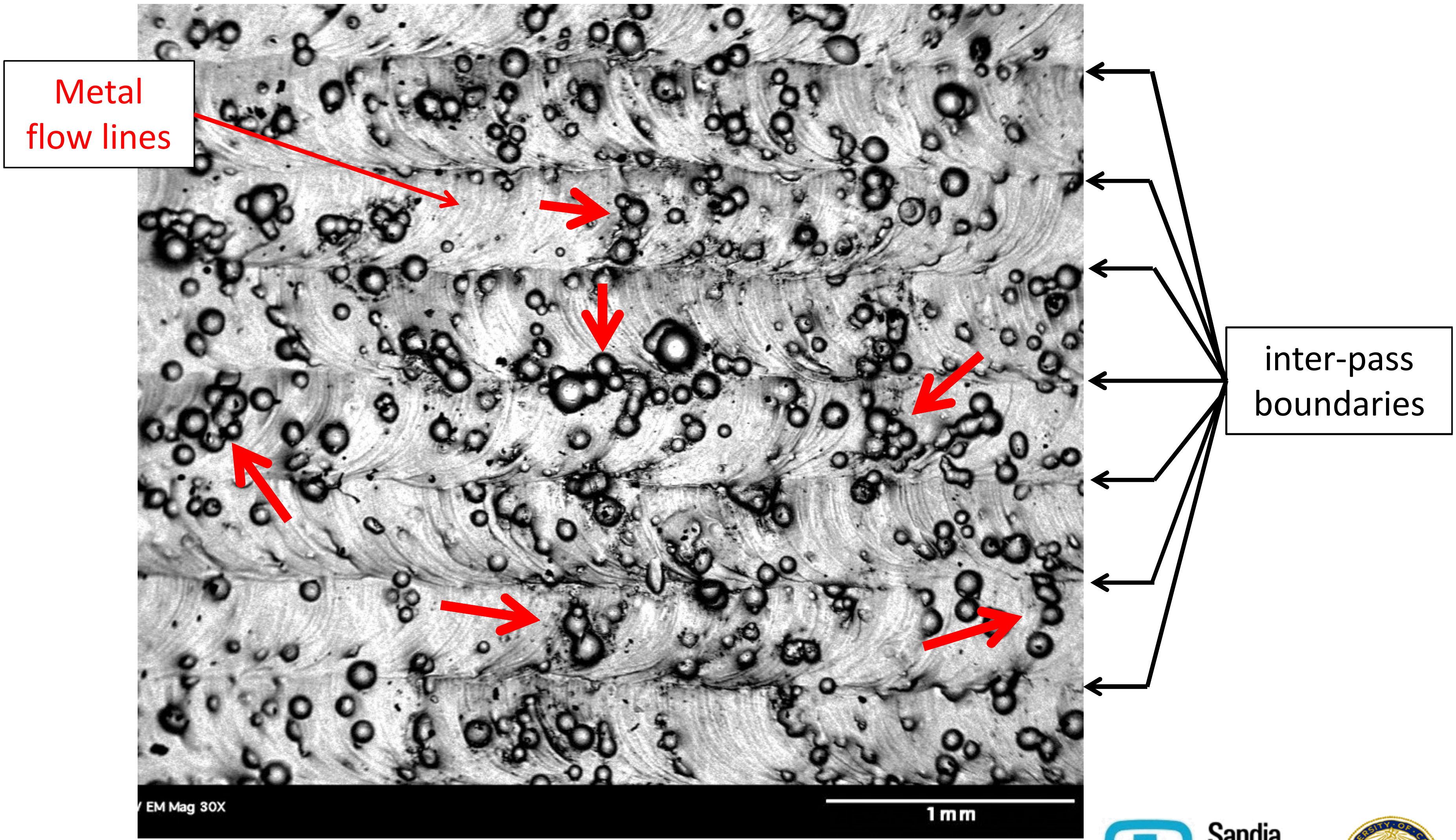






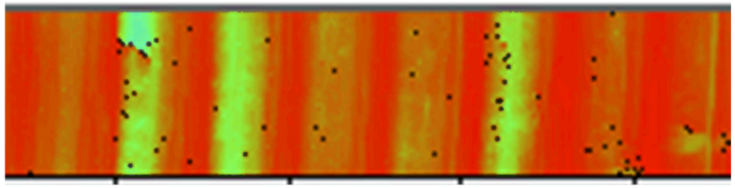
Average peak to valley is ~300um

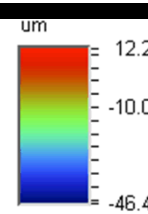
Unmelted powder piles up on printing surface, mostly along metal flow lines and inter-pass boundaries



Surface topography on the LENS printed thin disc is much rougher than those by machining

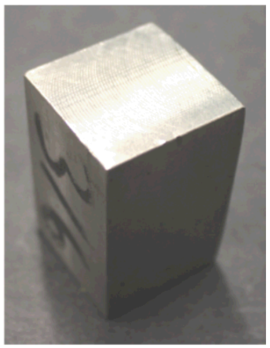
Mechanically machined

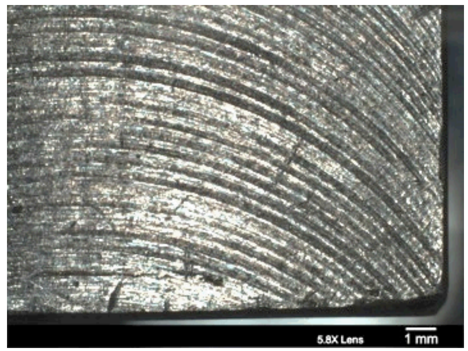


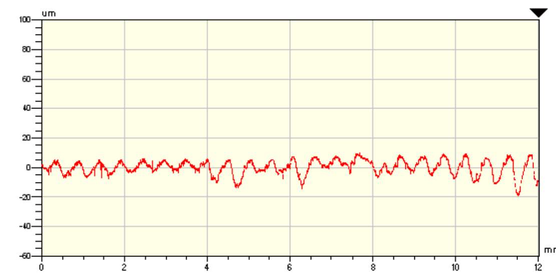


Rz: 37.60 um (Average)

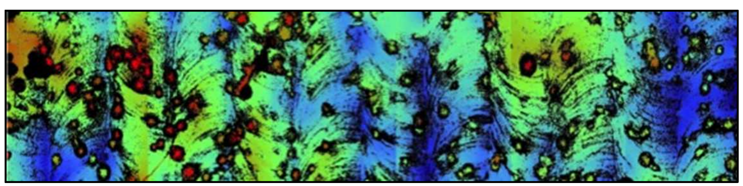
Rt: 58.54 um (Peak –valley)

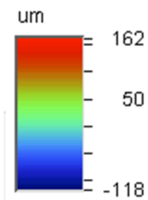






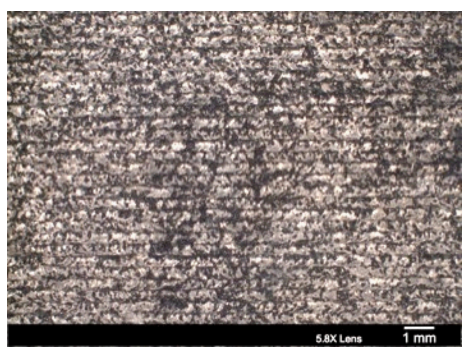
LENS printed



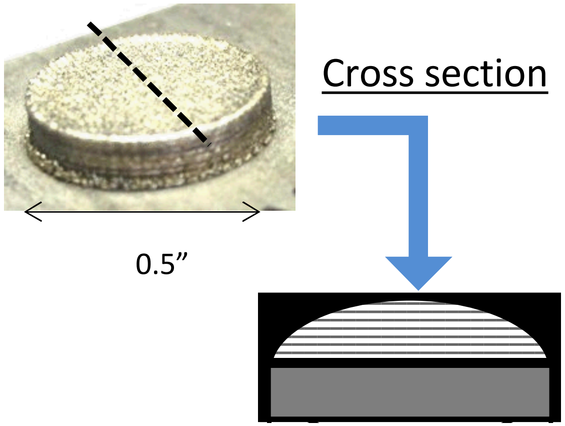


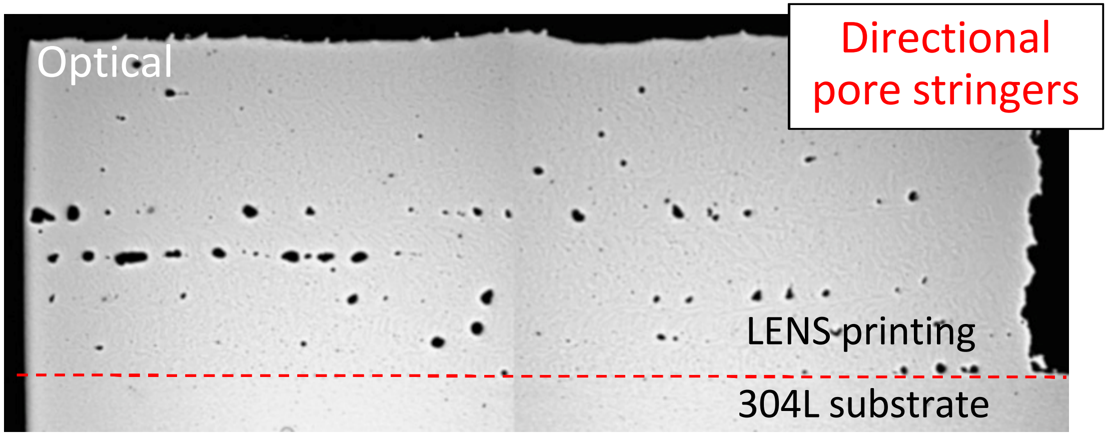
Rz: 326.24 um (Average)

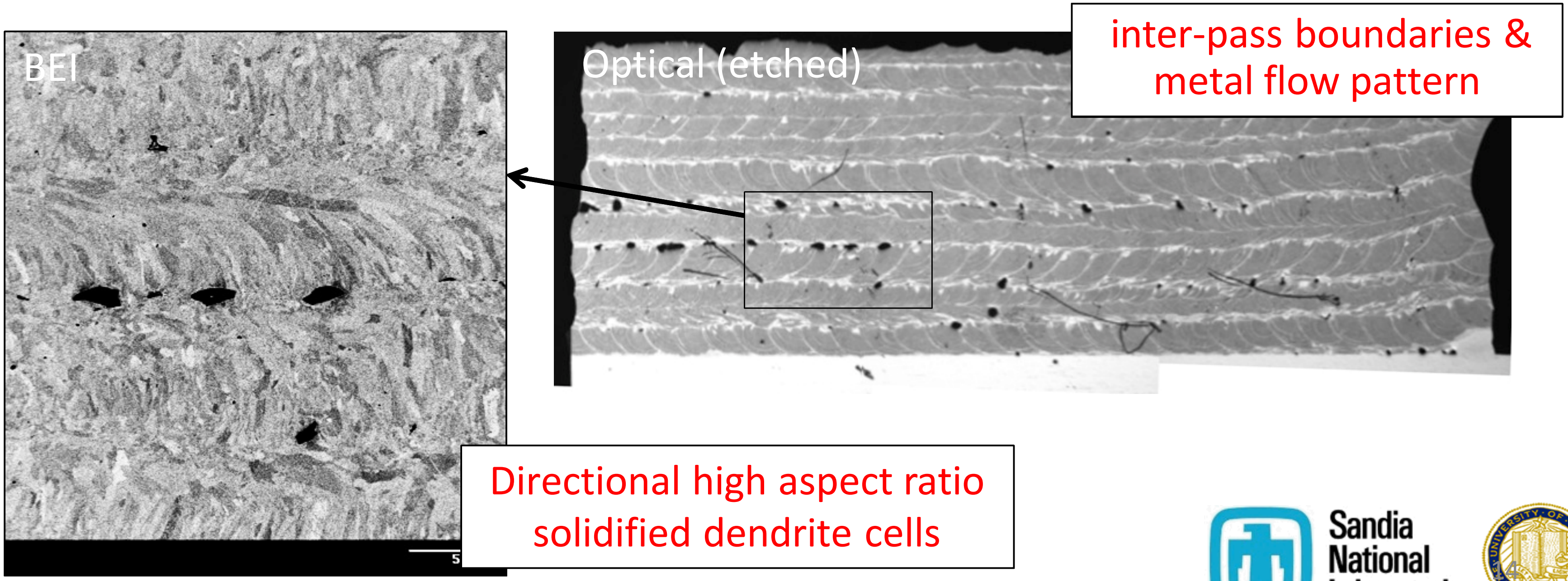
Rt: 418.07 um (Peak –valley)



Microstructure and structure integrity of 316Lss is defined by the process-induced characteristics

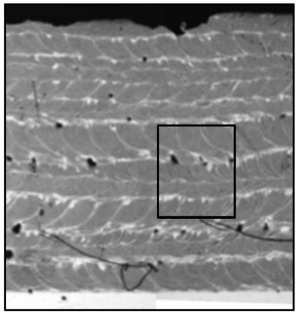


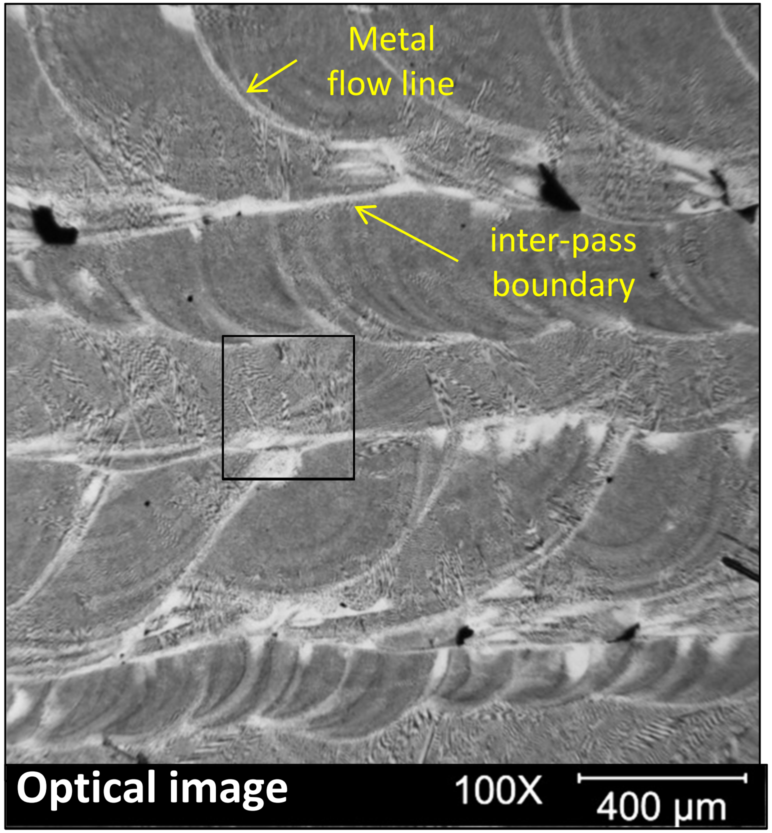


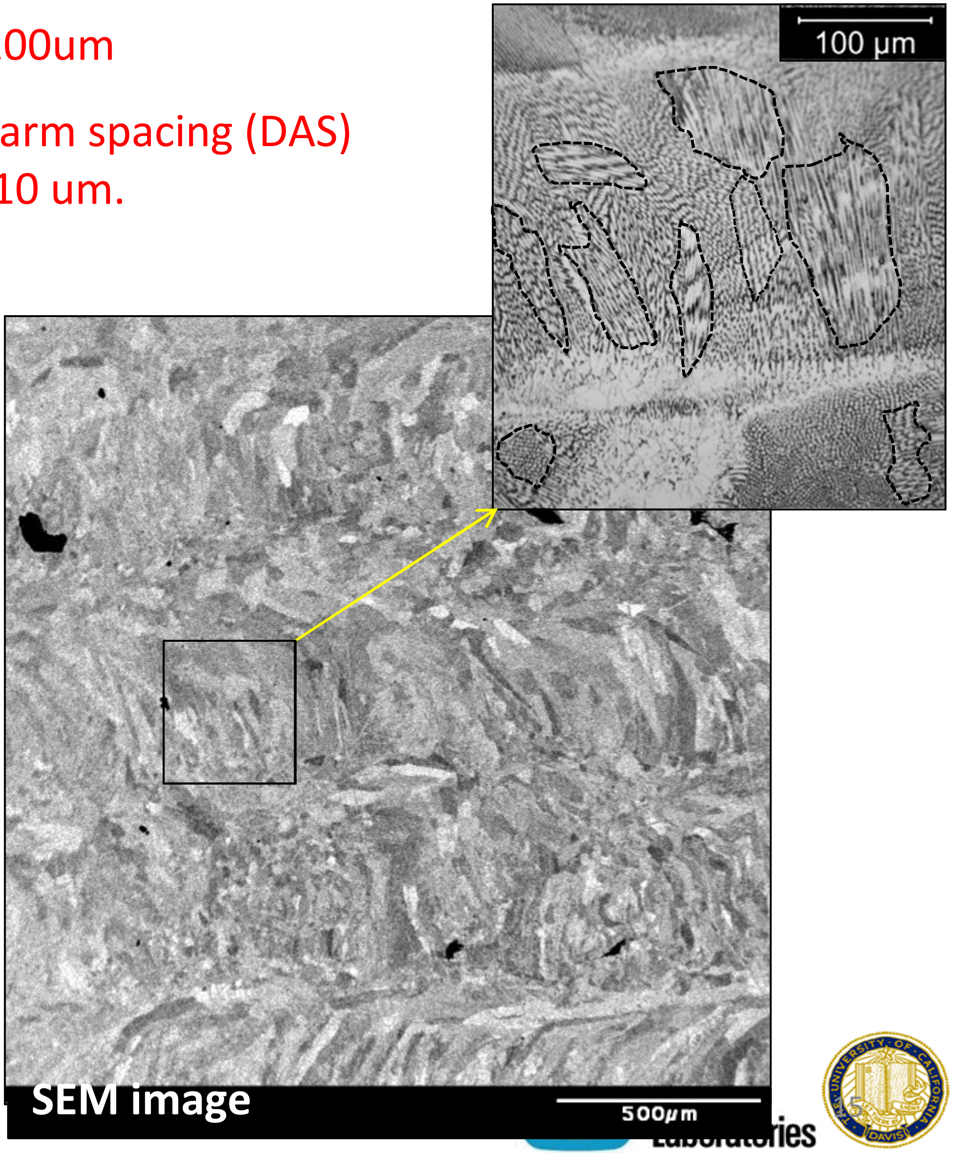


Optical/SEM images reveal the detail of inter-pass boundaries, metal flow, and solidified dendrite cells

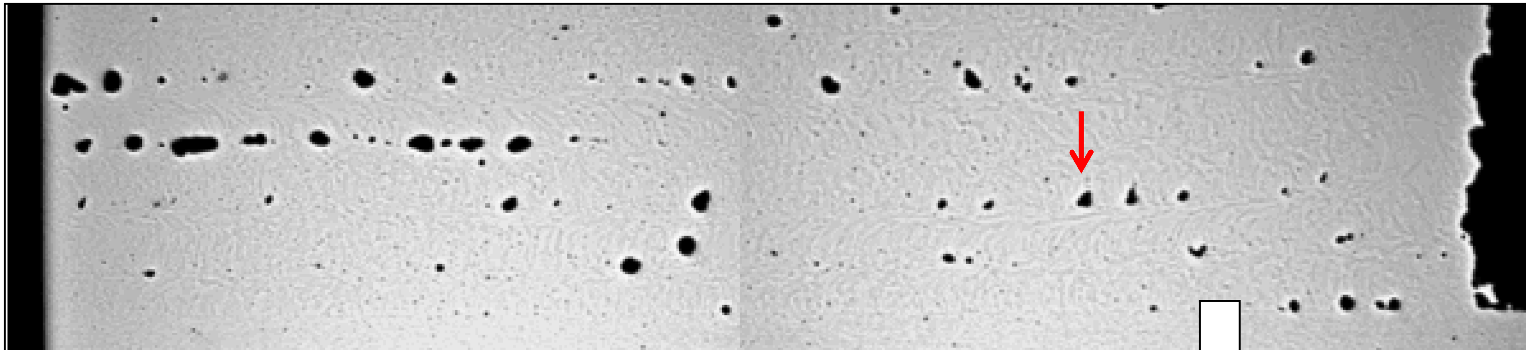
- Dendrite cell is 20-100um
- Secondary dendrite arm spacing (DAS) varied from <1.0 to 10 um.

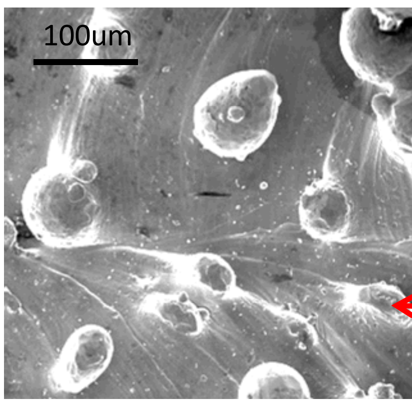


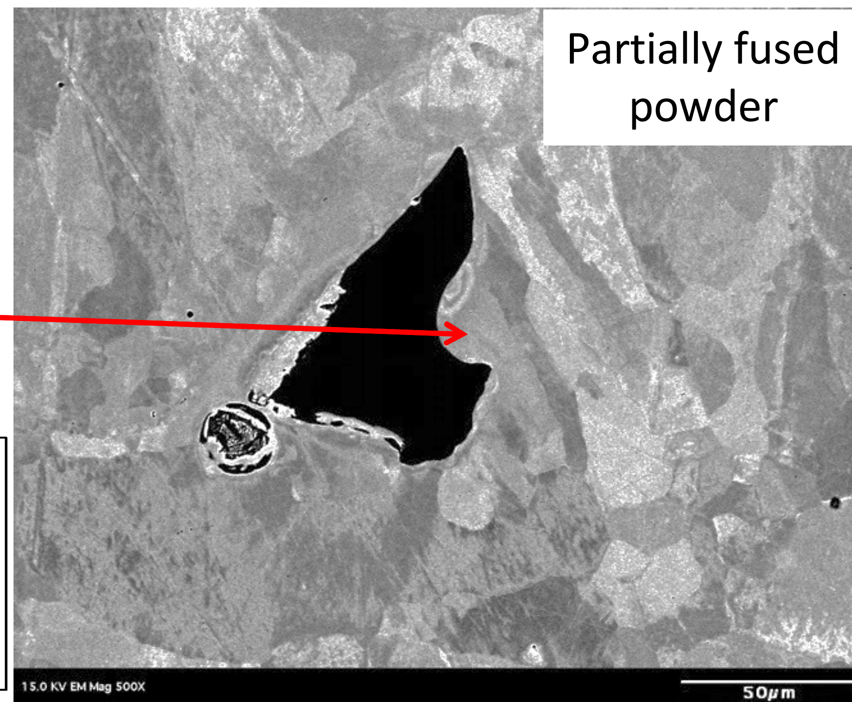




The observed gross pores are induced by the unmelted powder left in the inter-pass boundaries

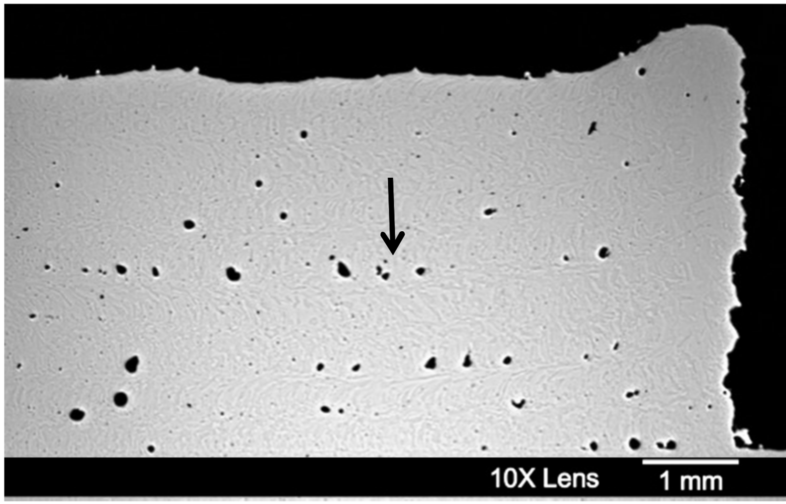


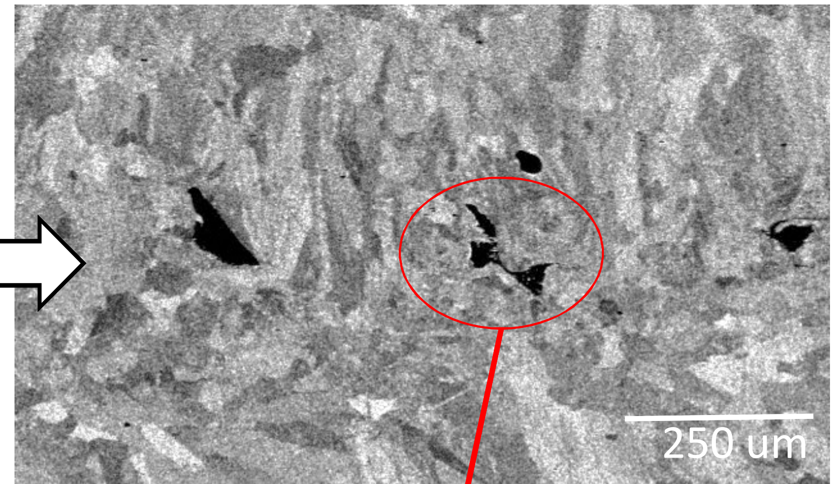


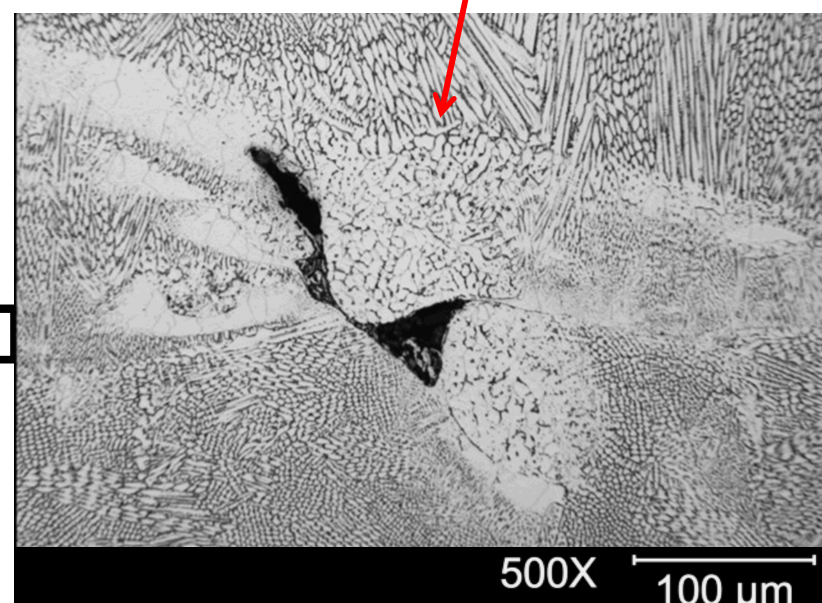


The inner pore contour seen in the cross section is consistent with those unmelted powder seen on the top surface.

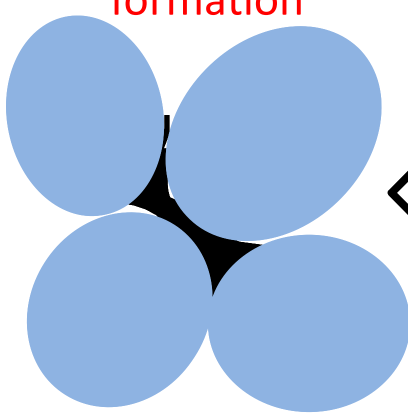
Schematic illustrates how the entrapped unmelted powder is responsible for the formation of gross inter-pass pore



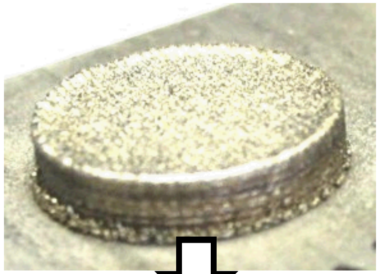


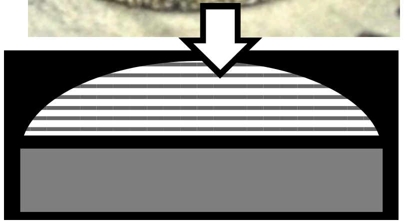


Schematic of dog bone pore formation

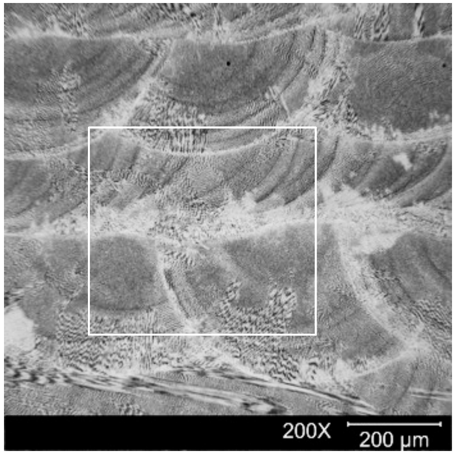


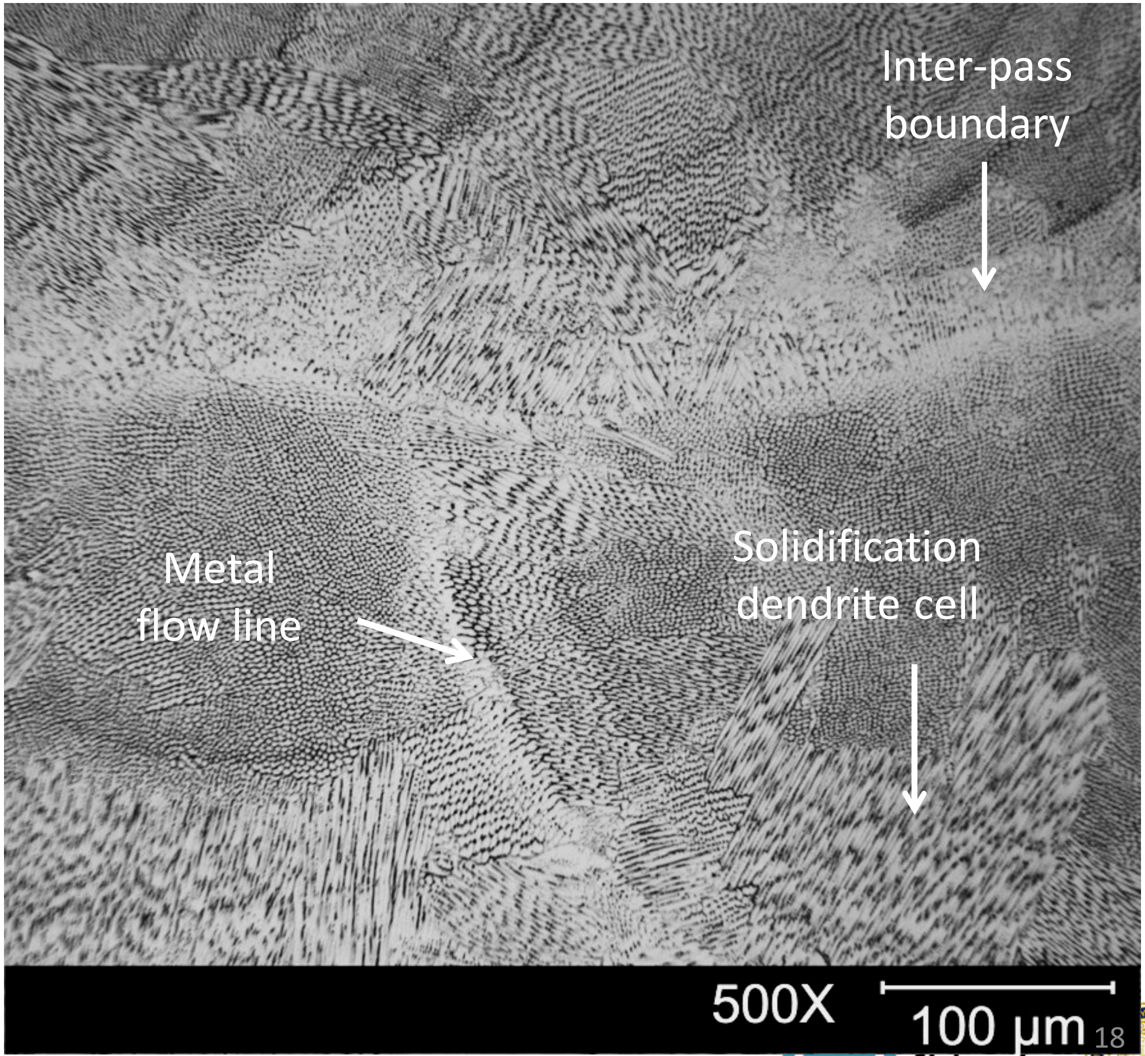
Consistent LENS-induced metallurgy requires a good insight into inter-passing/metal flow/solidification interaction





Typical microstructure of etched LENS printed cylinder





Summary

- LENS is effective to print prototyping design with complex net shape and dimension.
- Metallurgy and structural integrity of the LENS 316Lss is greatly dependent on thermal transport during powder melting, molten metal flow, and solidification.
- Surface topography of 3-D LENS printing is much rougher than those by mechanical machining, 300um vs 40um respectively.
- In order to control the physical metallurgy of LENS printing, thermal transport mechanism and its interaction among powder melting, metal flowing and solidification, must be understood.
- LENS process optimization to tailor surface topography, microstructure, and mechanical property is on-going.