The Consortium for Enabling Technologies and Innovation

Virtual Summer Meeting for Young Researchers

Correlation of Irradiation Responses and Microstructures in AM 316 Stainless Steels

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National Nuclear Security Administration

AM 316L SS preparation

Limited condition from Dr. Chen Sun at INL

316L SS Direct Energy Deposition process

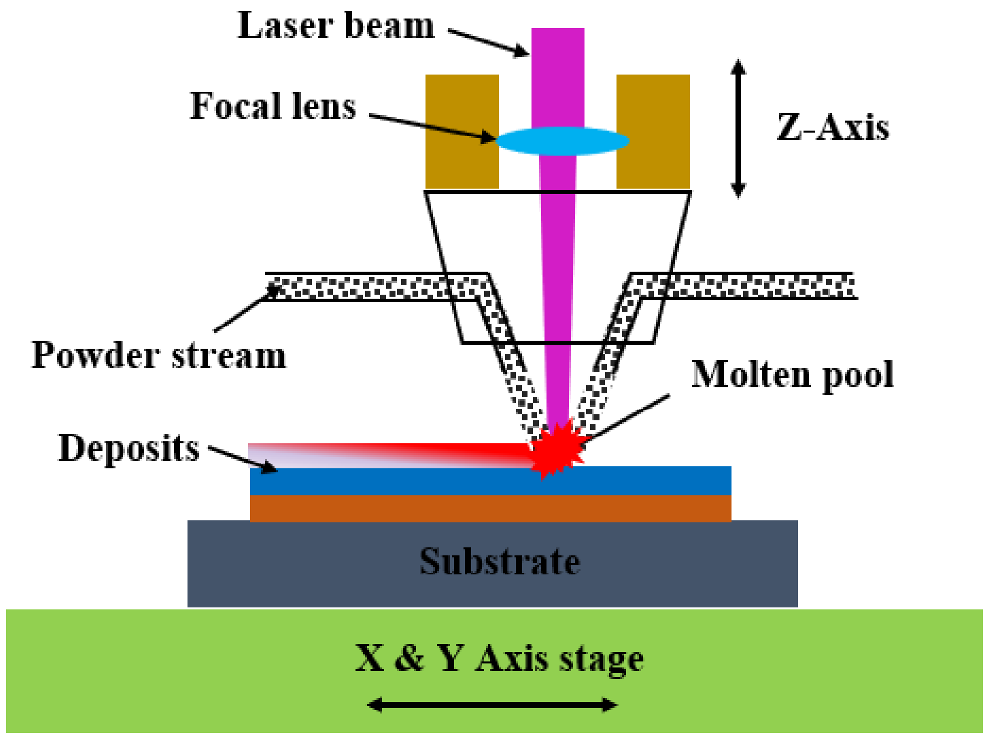
LENS MTS 500 printer from Optomec Inc.
316L SS powders from John Galt Steel
Laser power: 400W
Scanning speed of 12.7 mm/s and
Spot size of 600 µm in an argon atmosphere.

Systematic matrix from Dr. Dan Thomas at UW-Madison

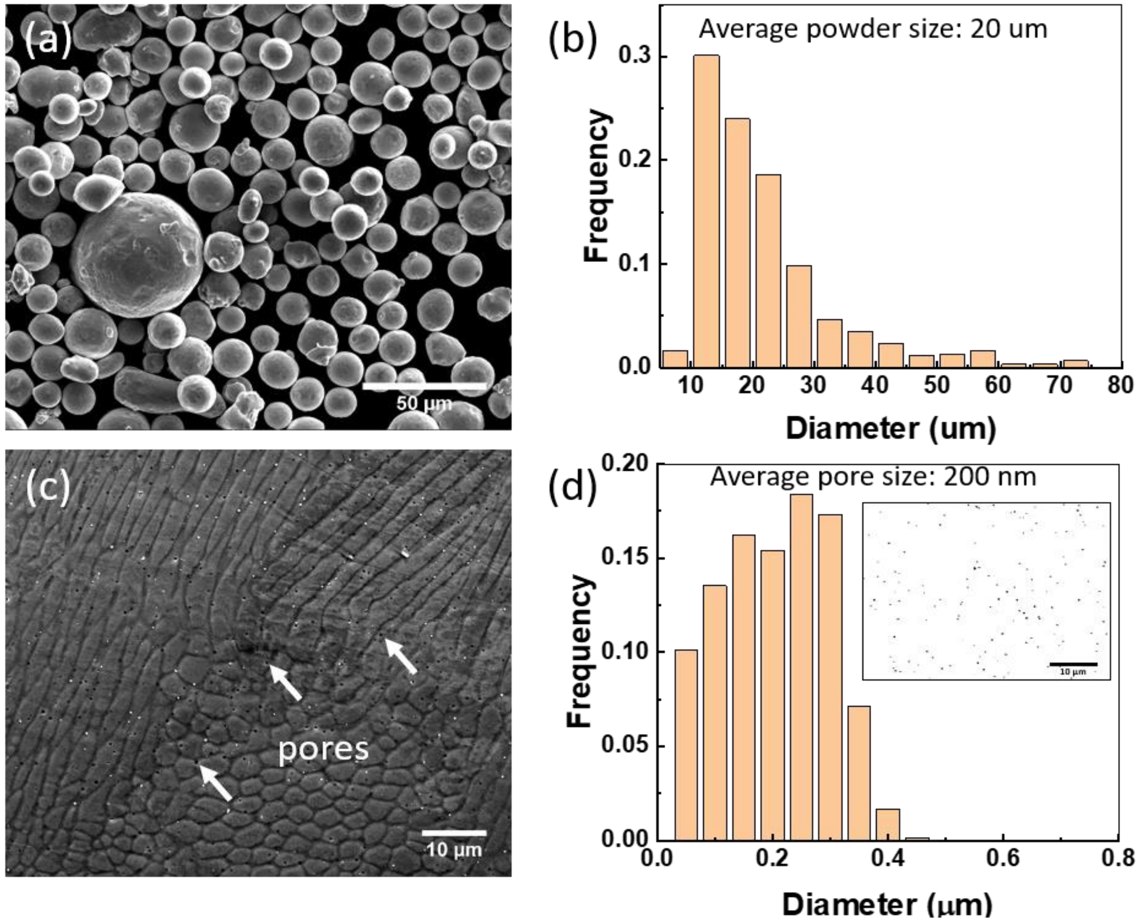
316L SS Powder Bed Fusion Process

S.No.	Laser Power (W)	Scanning Speed (mm/s)	Hatch Spacing (mm)	Layer Thickness (mm)	Volumetric Energy Density (J/mm3)
1	120	600	0.07	0.02	142.86
2	120	600	0.09	0.02	111.11
3	120	600	0.11	0.02	90.91
4	120	800	0.11	0.02	68.18
5	200	600	0.11	0.02	151.52
6	200	800	0.11	0.02	113.64
7	200	1300	0.11	0.02	69.93
8	260	800	0.11	0.02	147.73
9	260	1300	0.11	0.02	90.91

DED AM 316L

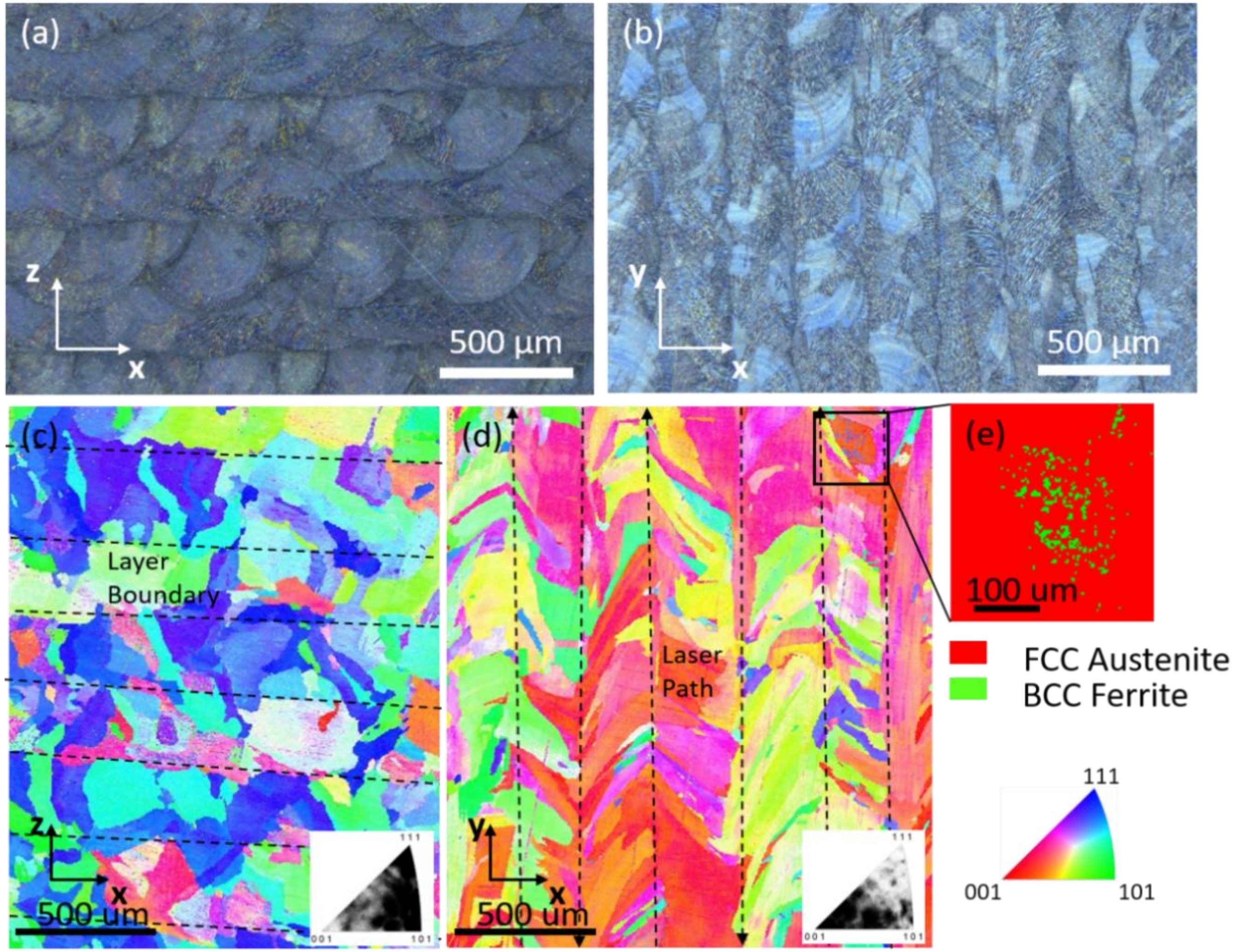


Laser beam
Focal lens
Z-Axis
Powder stream
Molten pool
Deposits
Substrate
X & Y Axis stage

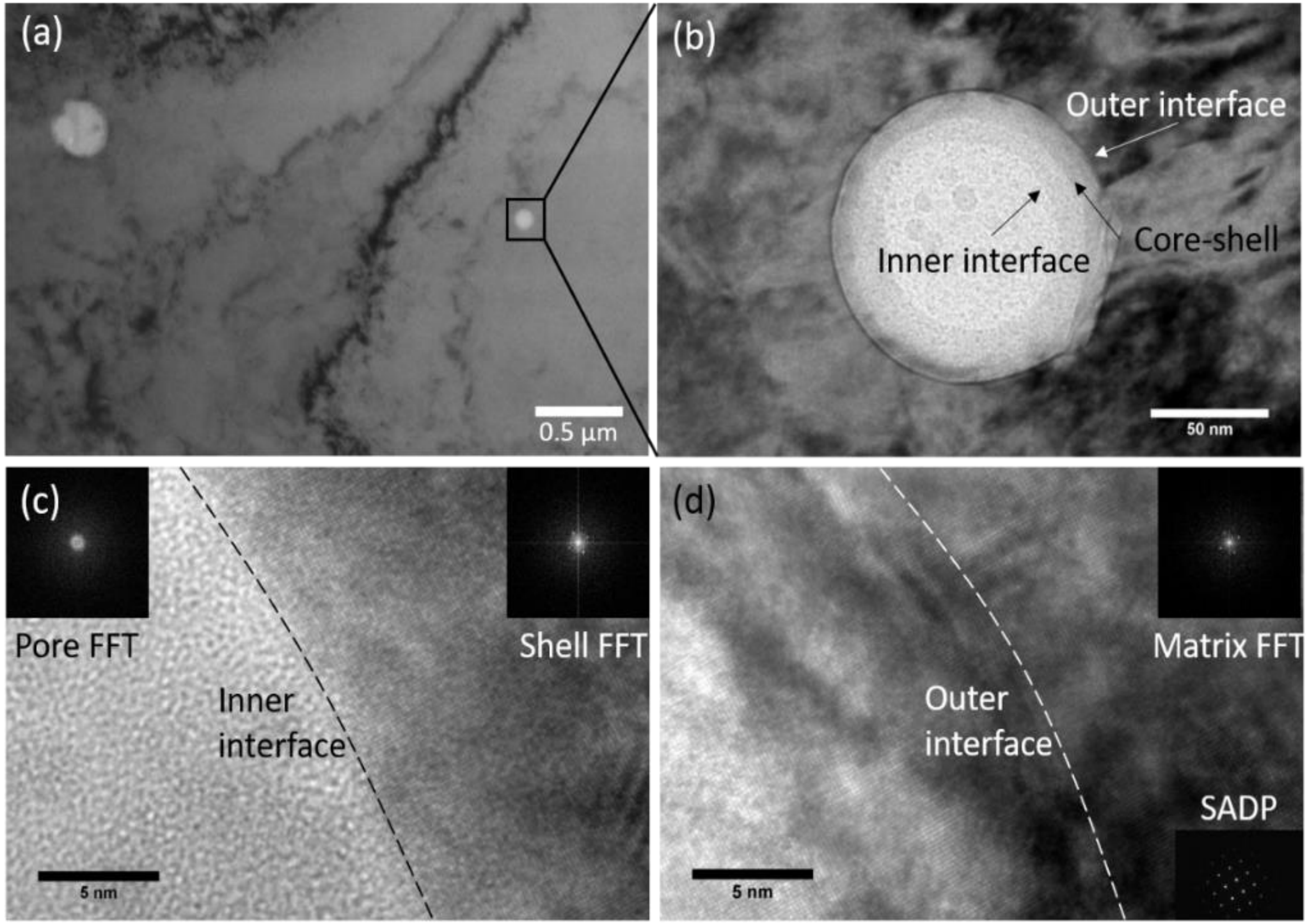


(a)
50 µm
(b)
Average powder size: 20 um
Frequency
Diameter (um)
(c)
pores
10 µm
(d)
Average pore size: 200 nm
Frequency
Diameter (µm)

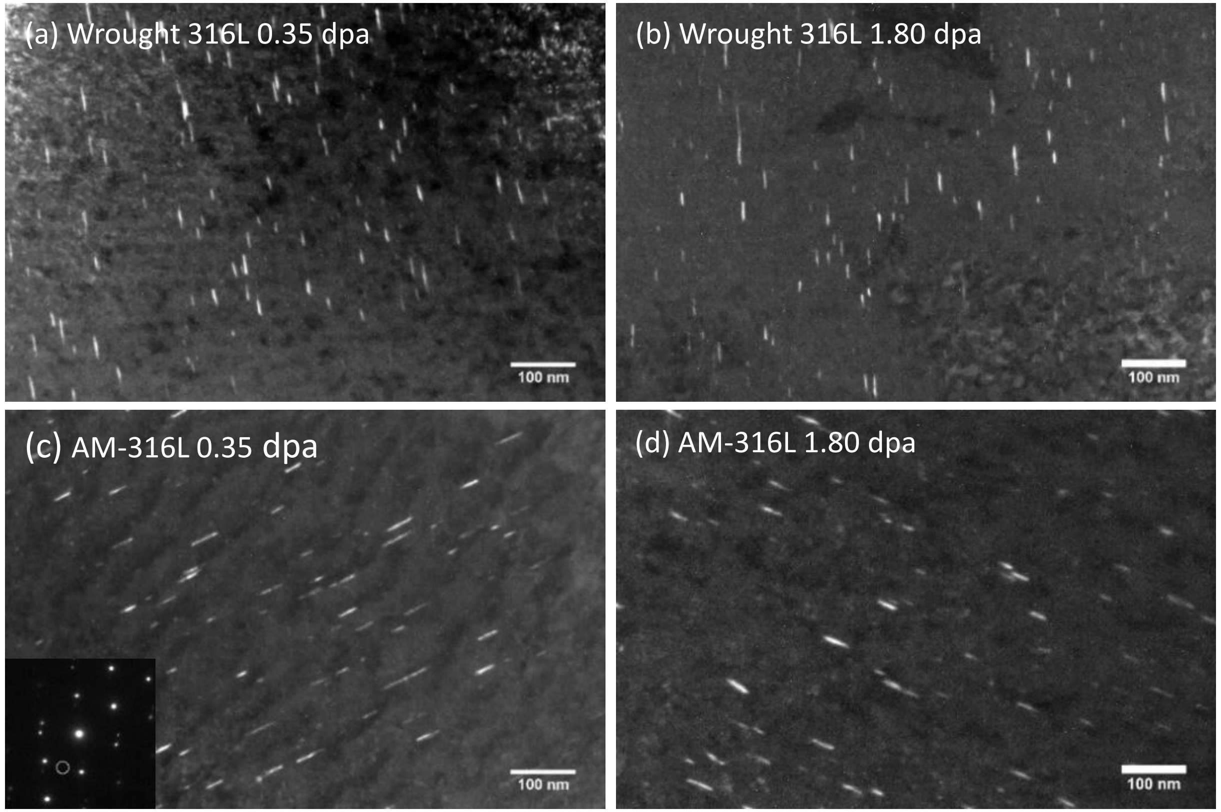
DED AM 316L

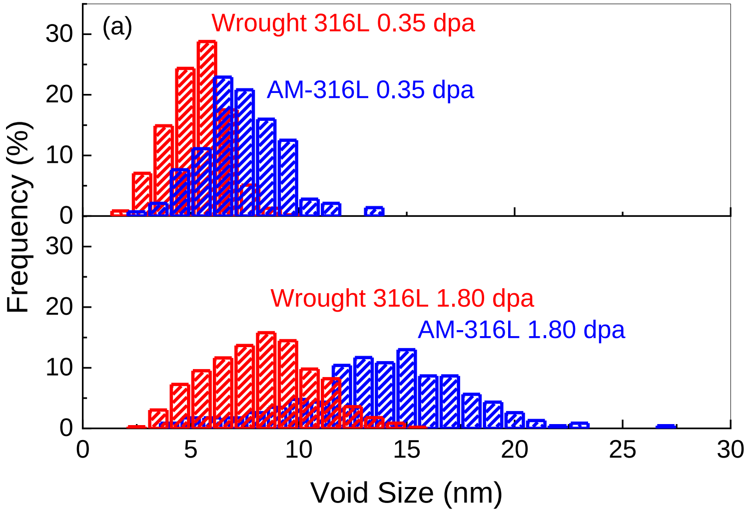

(a)
z
x
500 µm
(b)
y
x
500 µm
(c)
Layer
Boundary
z
x
500 um
(d)
Laser
Path
y
x
500 um
(e)
100 um
FCC Austenite
BCC Ferrite
111
001
101

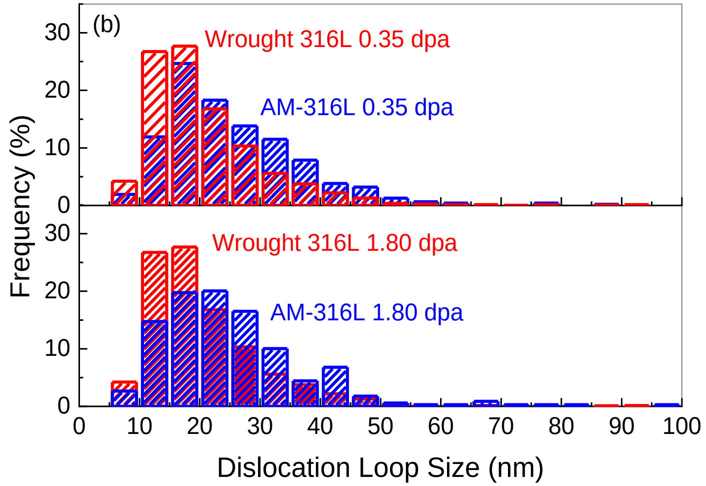
DED AM 316L


(a)
0.5 µm
(b)
Outer interface
Inner interface
Core-shell
50 nm
(c)
Pore FFT
Shell FFT
Inner
interface
5 nm
(d)
Matrix FFT
Outer
interface
SADP
5 nm

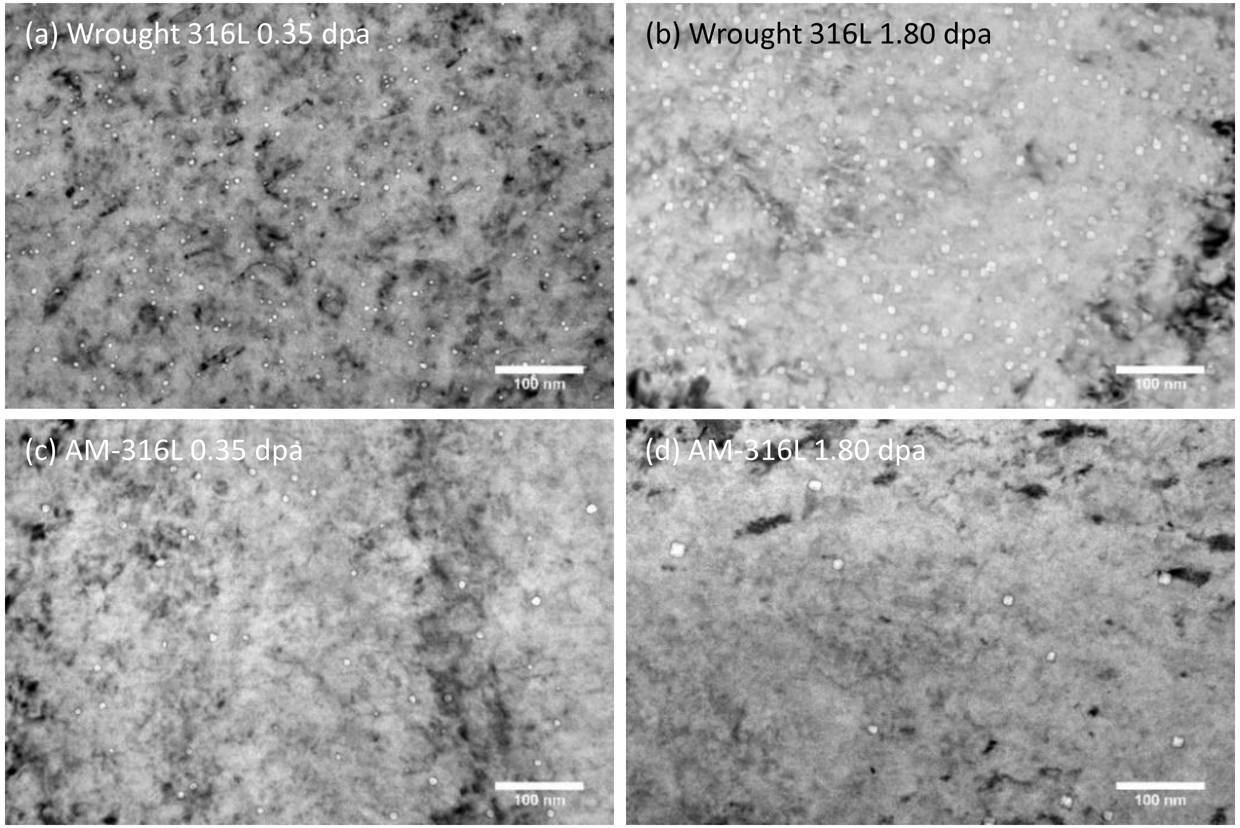
Proton irradiated DED AM 316L

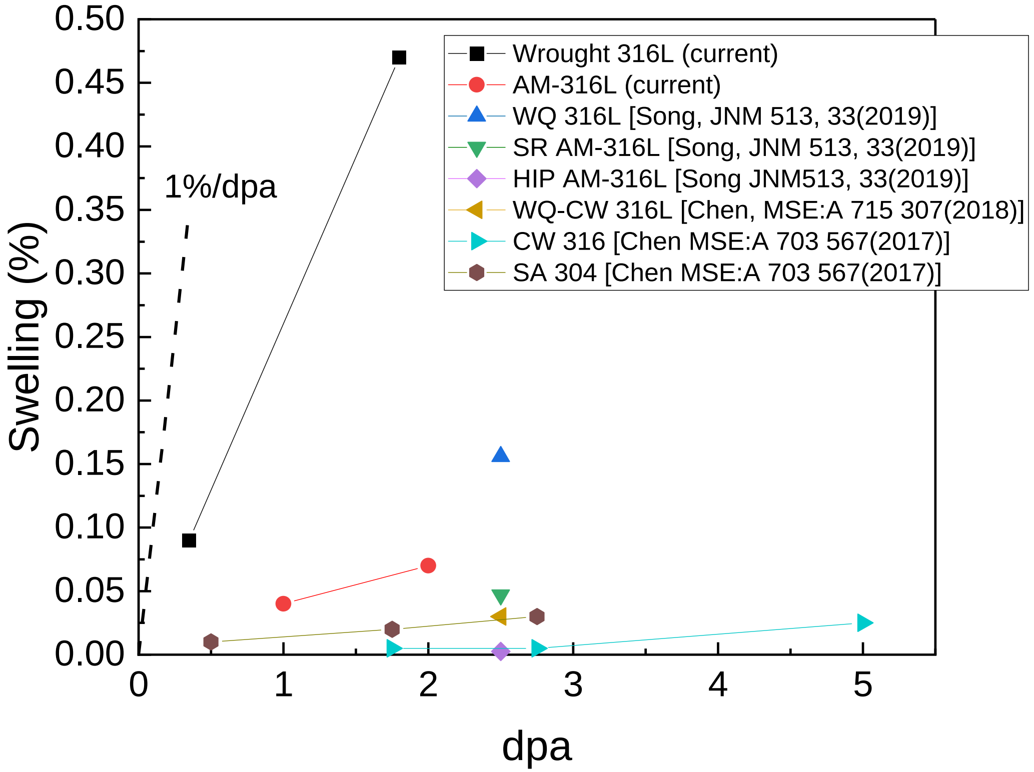






Proton irradiated DED AM 316L





UW- Madison PBF AM 316L

Before Polishing

Printing parameters:

- **Laser Power:** 120 W
- **Scanning Speed:** 600 mm/s
- **Hatch Spacing:** 0.07 mm
- **Layer Thickness:** 0.02 mm

After Polishing

Electropolishing parameters:

- **Solution:** 5% Perchloric Acid ($HClO_4$) in Methanol
- **Applied Voltage:** 25 V
- **Temperature:** -35° C
- **Polishing time:** 12 s

Helium implantation:
to speed up void formation

Ion beam condition

Beam: 100 keV He

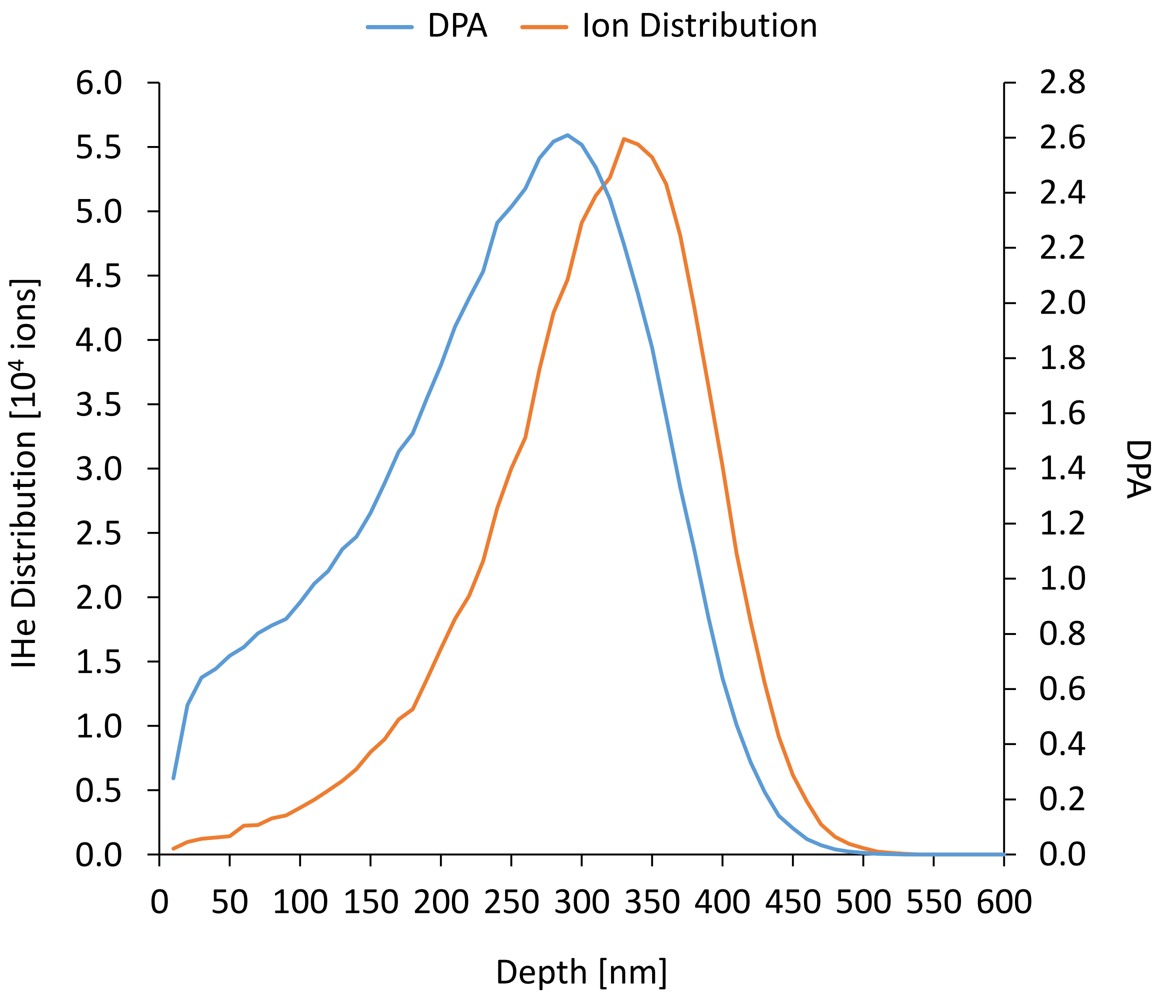
Raster beam (X: 0.25Hz, Y: 3.43 Hz)

Beam area: 7mm x 8.5mm

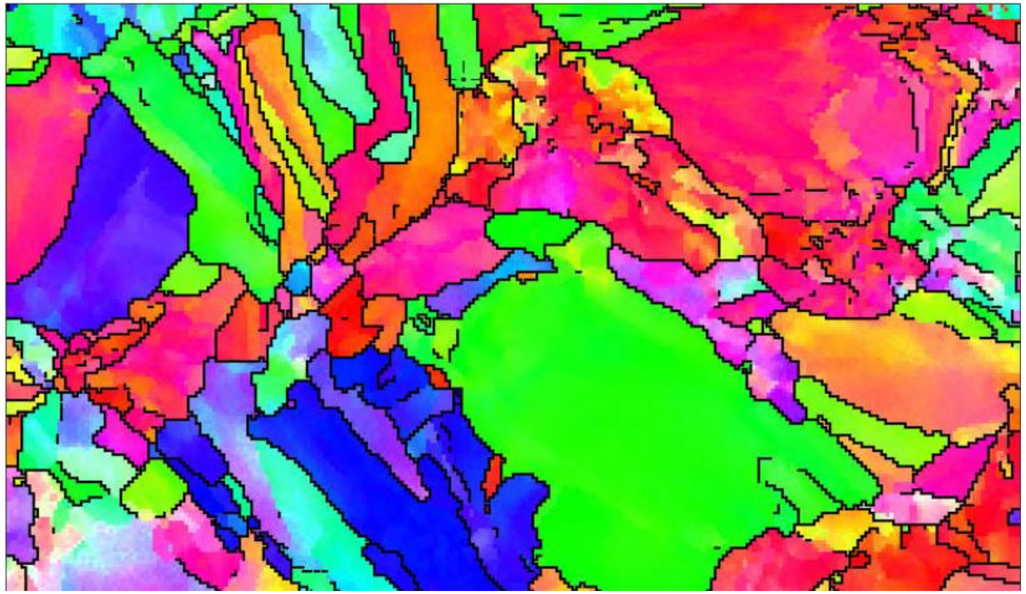
Beam current: 3 μA ($3.15x10^{13}$ ions/cm^2/s)

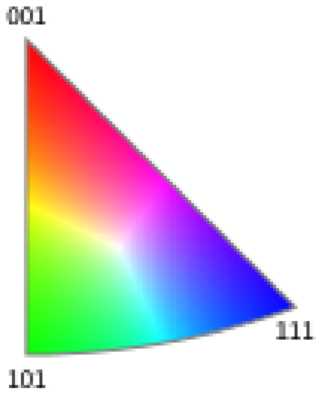
Temperature: 300° C

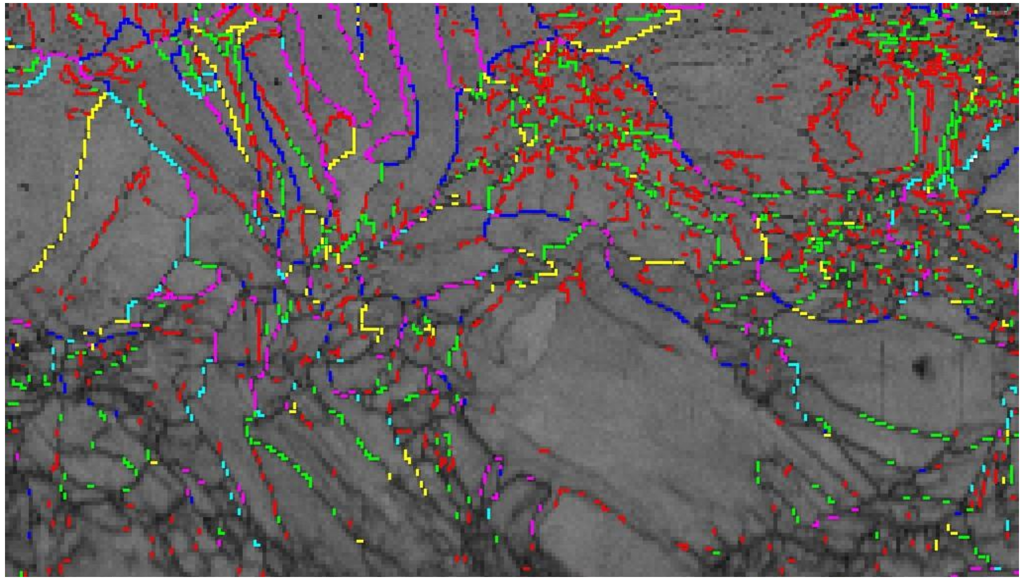
Fluence: $1x10^{17}$ ions/cm^2



After helium ion irradiation, using EBSD to guide FIB location: numerous site selective characterization to study swelling dependence on grain boundaries







Colors:
4° -10° Red
10° -20° Green
20° -30° Yellow
30° -40° Blue
40° -50° Fuchsia
50° -60° Aqua

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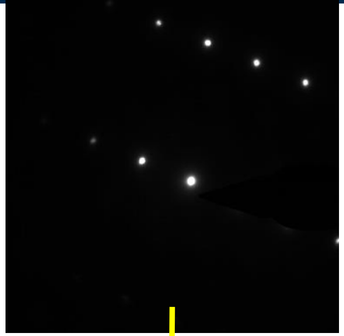
TEM Results:
Area without pore

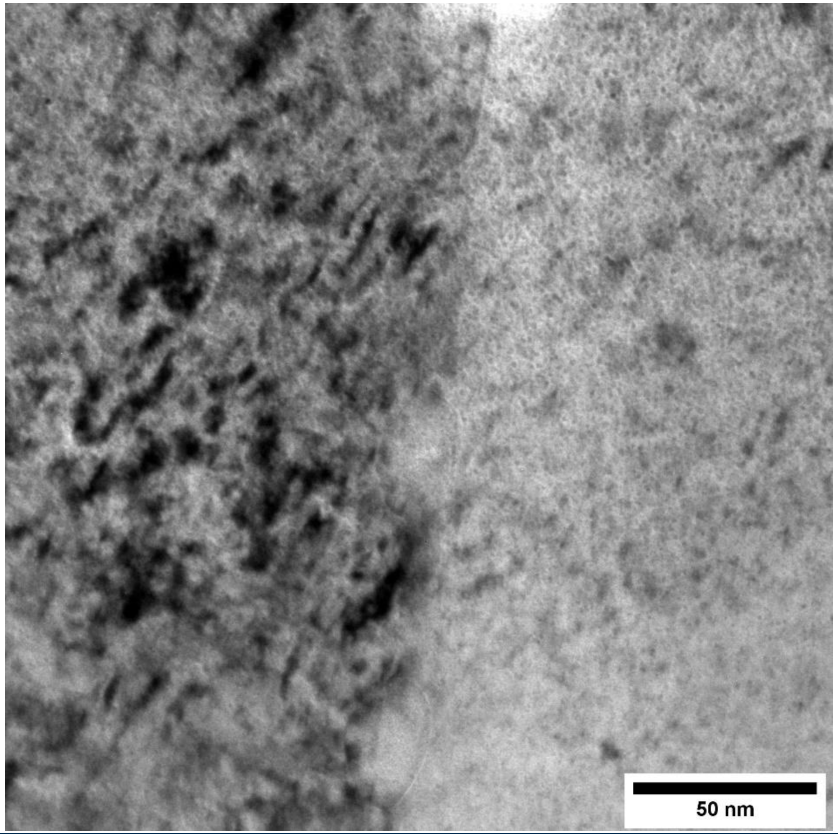


Left grain: α=-7.09 °, β=-4.73°

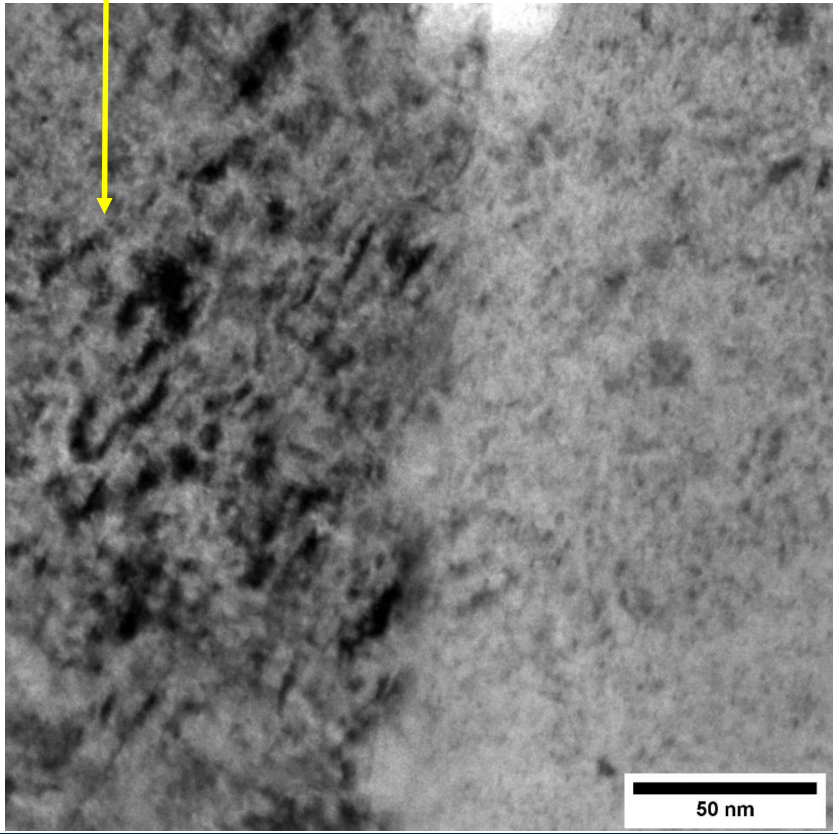
Right grain: α=7.46 °, β=0.08°

△=15.32 °

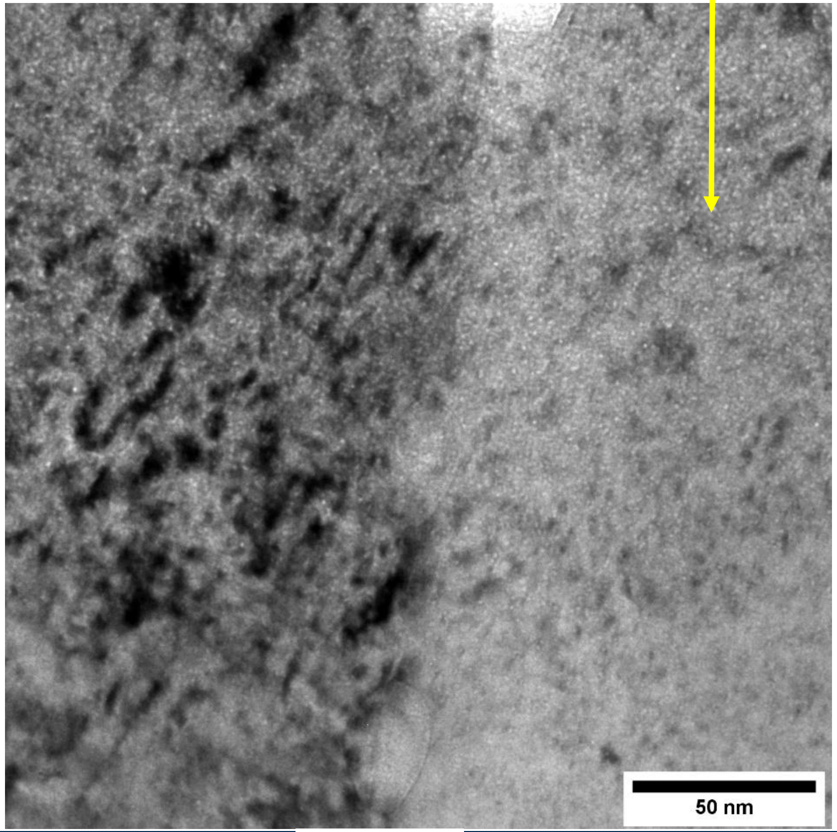
Over-Focused



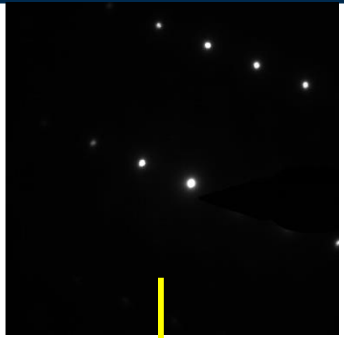
Focused



Under-Focused

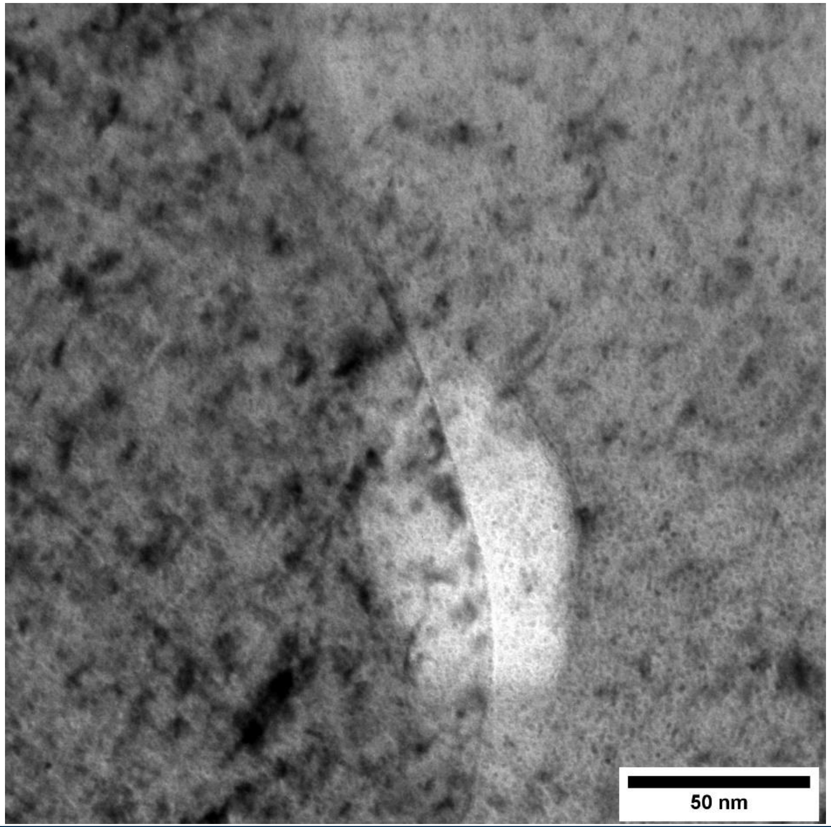


TEM Results: Area with pore

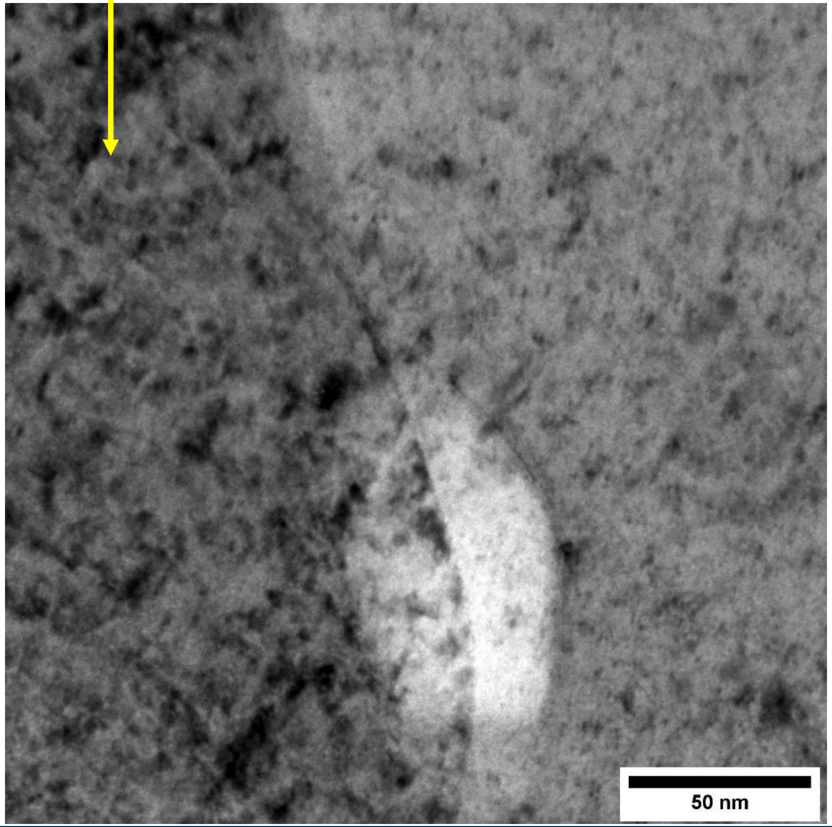


Left grain: α=-7.09 °, β=-4.73°
Right grain: α=7.46 °, β=0.08°
△=15.32 °

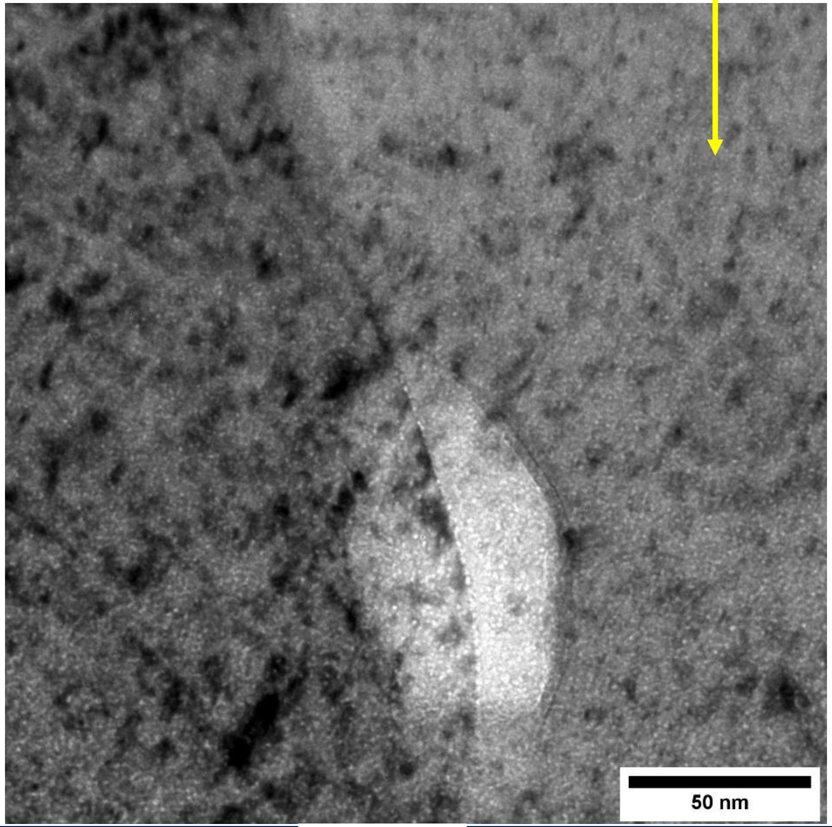
Over-Focused



Focused



Under-Focused



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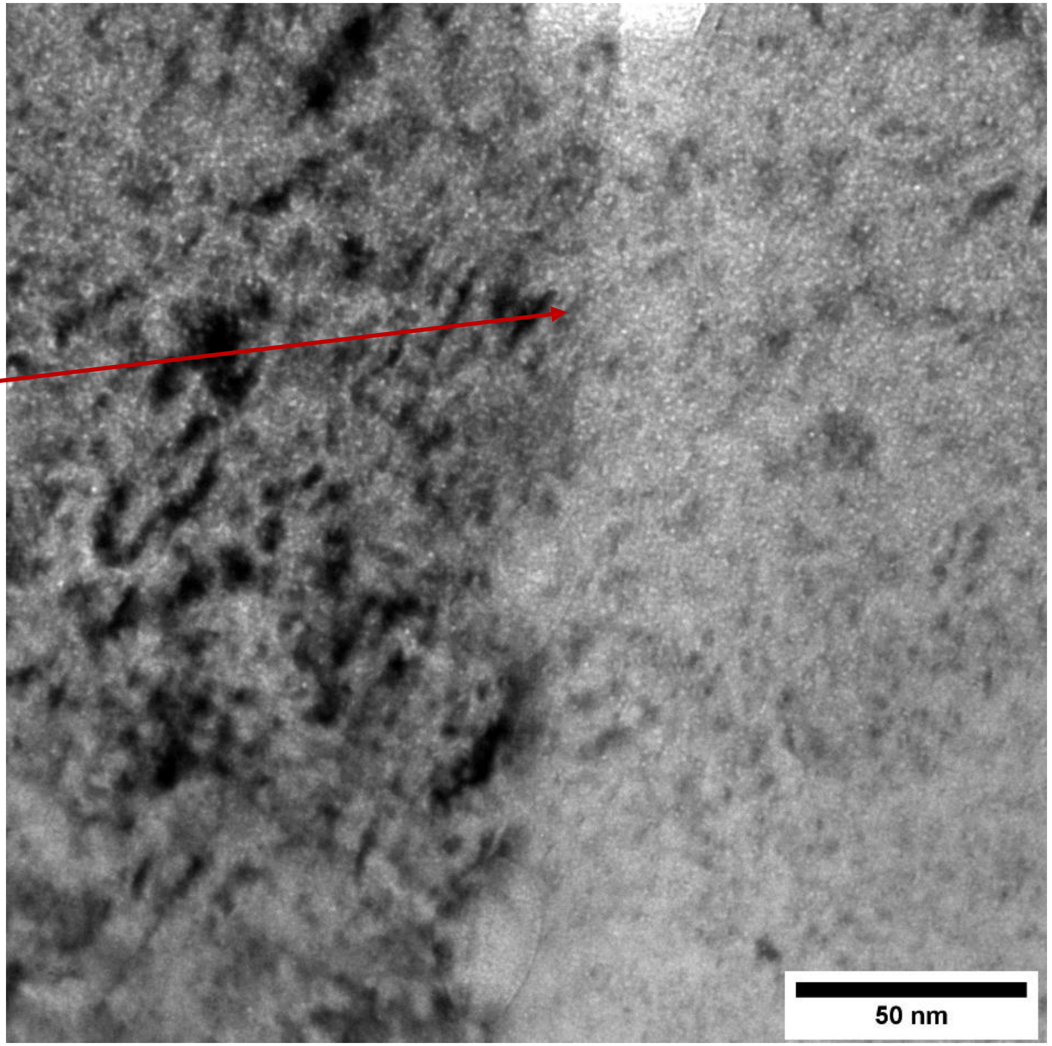
TEM Results:

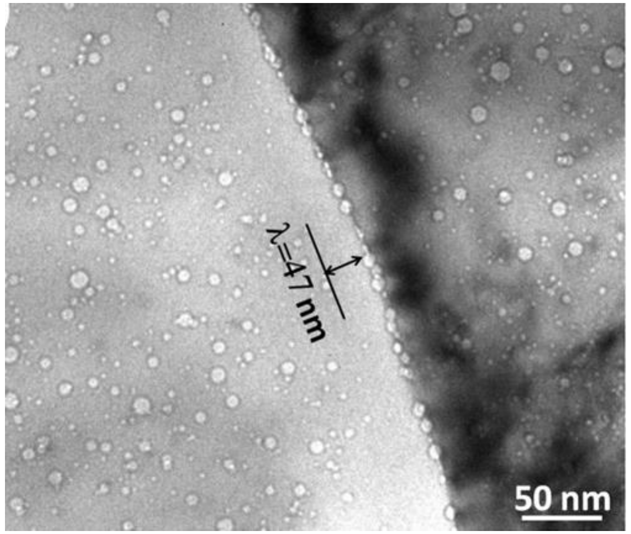
Under-Focused

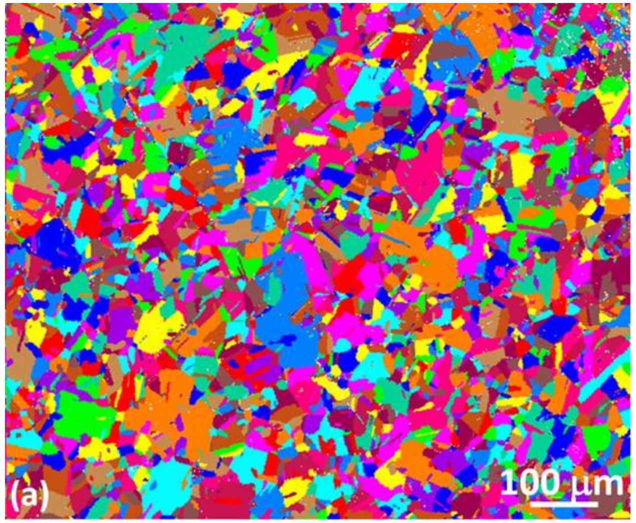


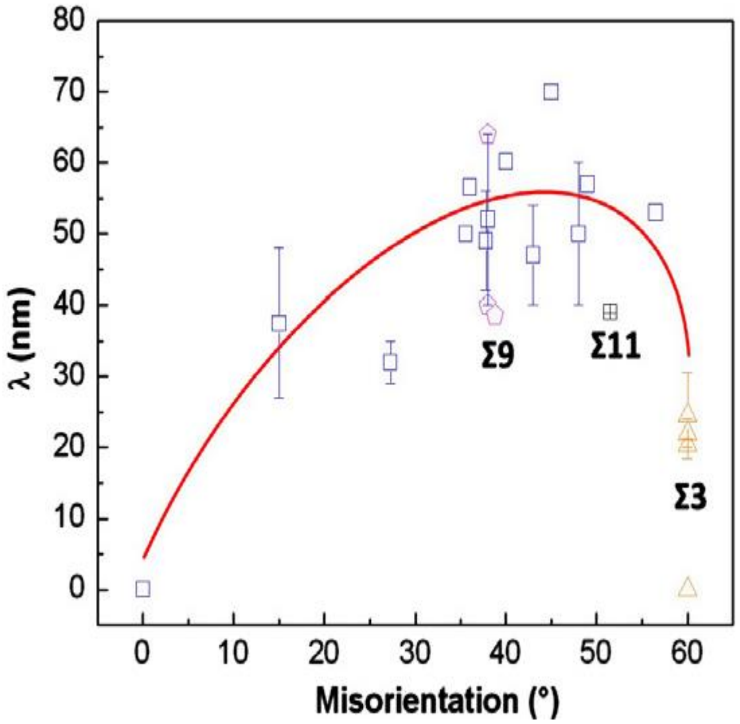
Bubble aggregation can be observed at boundary in both areas.

No noticeable depletion zone: expected for small angle boundaries

He into Cu







Data taken from Han et al., 2012

Boundary sink efficiencies depend on boundary angles: to be tested in AM steels

Testing Matrix of UW-Madison 316L AM samples

Temperature	Irradiation	Status	Goal
300 C	Helium ion implantation to 1×10^{17} /cm^2	Irradiation completed, FIB/TEM delayed due to the virus	The key is to study void depletion as a function of boundary misorientation angles. The irradiation temperature is low avoid grain growth.
400 C	1 dpa proton irrad.	Irradiation finished FIB/TEM delayed due to the virus	The key is to study boundary segregation as a function of misorientation angles. The temperature is high enough to induce segregation, but low enough to avoid grain growth)
	3 dpa proton		
	5 dpa proton		
575 C	50 dpa Fe	Scheduled in July	The key is to swelling tolerance for multiple samples manufactured under different conditions. The temperature is at maximum swelling temperature.
	100 dpa Fe		
	150 dpa Fe		

Acknowledgement

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