CANFSA

Center for Advanced Non-Ferrous Structural Alloys
An Industry/University Cooperative Research Center

Project 36E-L: In-Situ Characterization of Microstructural Evolution During Simulated Additive Manufacturing in Model Alloys

Fall Meeting

October 13th – 15th 2020

- Student: Brian Rodgers (Mines)
- Faculty: Amy Clarke (Mines)
- Industrial Mentors: Edwin Schwalbach (AFRL), Neil Carlson (LANL)
- Other Participants: Jonah Klemm-Toole (Mines), Joe McKeown (LLNL), Alain Karma (Northeastern Univ.)

Project 36E-L: In-Situ Characterization of Microstructural Evolution During Simulated Additive Manufacturing in Model Alloys

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- Student: Brian Rodgers (Mines)
- Advisor(s): Amy Clarke (Mines)

Project Duration
PhD: September 2019 to March 2023

- Problem: Aerospace components are difficult to produce conventionally, but the effects of additive manufacturing (AM) on microstructural evolution are not understood enough to replace conventional manufacturing.
- Objective: Develop an understanding of solidification behavior in model alloys under AM conditions by *in-situ* characterization.
- Benefit: Microstructural control for additive manufacturing of aerospace components.

Recent Progress
- Top-down imaging of as-solidified melt pools
- Qualifying exam

Metrics

Description	% Complete	Status
1. Literature review	25%	●
2. Analysis of APS beam line data	40%	●
3. Analysis of Dynamic Transmission Electron Microscopy (DTEM) of rapid solidification	0%	●
4. Simulation of experimental conditions	15%	●
5. Complementary *ex-situ* characterization	15%	●

Industrial Relevance

Enhanced microstructure/properties:

- Control during AM

Applications:

- Turbine components
- Aerospace components

Benefits:

- Faster production time
- Greater geometric flexibility
- Reduced processing cost
- Enhanced performance
- Low volume/lean manufacturing and customization

Left photo courtesy of Wikimedia, right photo courtesy of NASA

Model Alloys of Choice

- Two alloy systems:
  - Ni-Al-Mo
  - Al-Ag
- Ni-base system consists of two alloys with same equilibrium γ' volume fraction supplied as single crystals
  - R2: Ni-6.6Al-1.9Mo (at%)
  - R4: Ni-2.8Al-22.2Mo (at%)
- Al-Ag binary system consists of two different fractions of silver
  - Al-10Ag (at%)
  - Al-18Ag (at%)

APS Experiments

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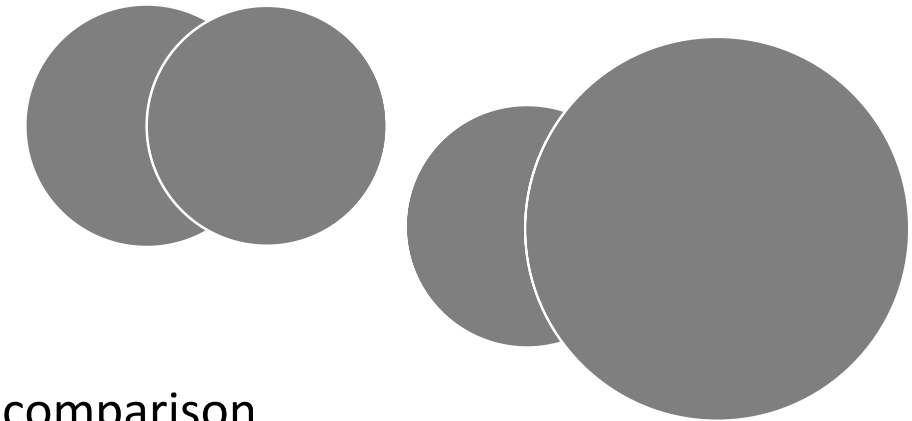
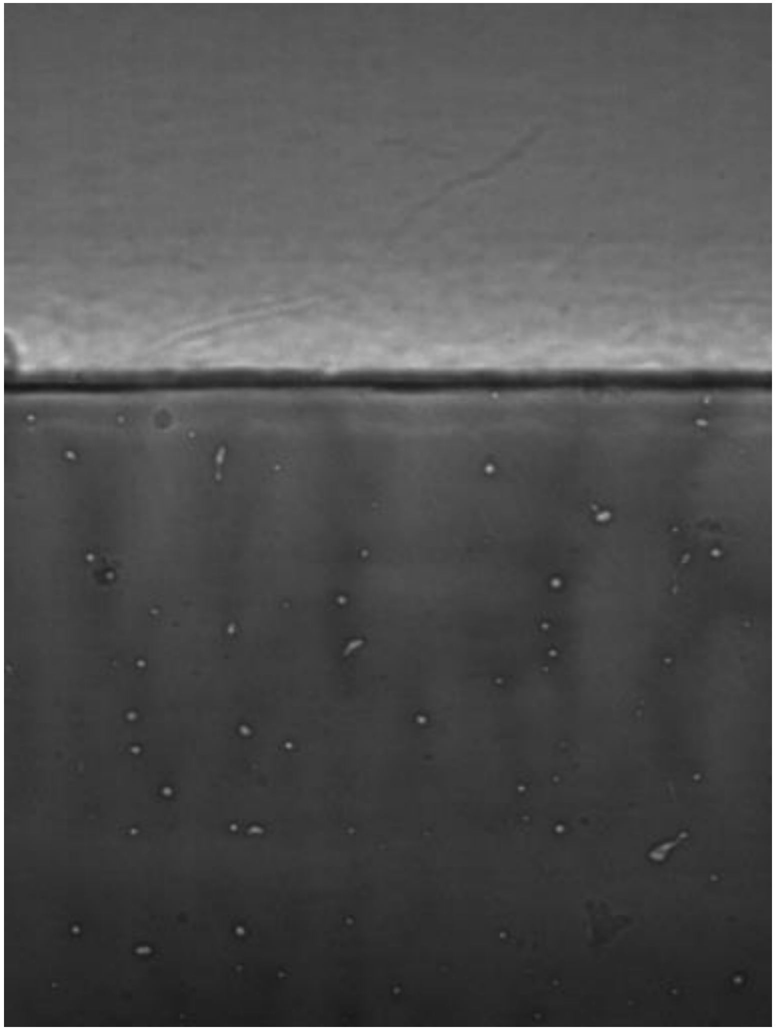


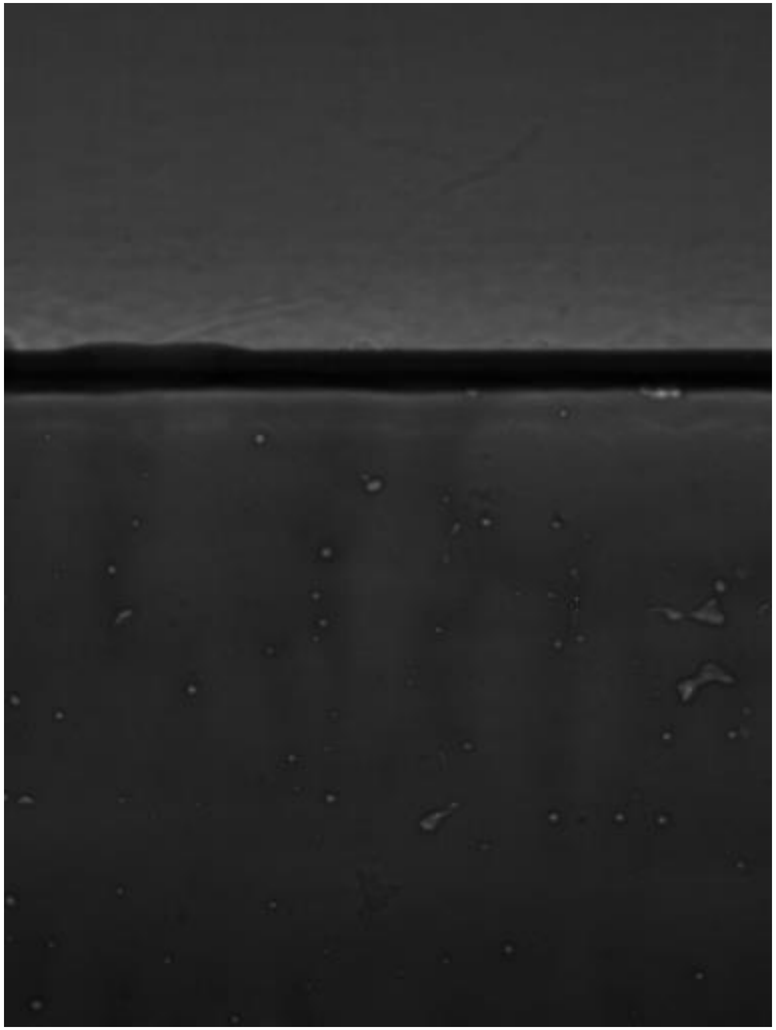
- R2 and R4 alloys:
  - Rasters at constant heat input
  - Overlapping spot melts
- Al-Ag system:
  - Rasters and re-rasters for DTEM comparison

Alloy	Beam power [W]	Raster speed [m/s]	Notes
R2 [110], R2 [111], R4[100], R4 [110]	253.9	1.6	
	139.4	0.5	
	47.8	0.1	
	82.1/82.1	Spot melt	Edge of second pool intersects middle of first
	82.1/253.9	Spot melt	
R2 [110]	517.1	1.6	
	253.9	1	
R4 [100]	517.1	1.6	
	368.3	1.6	
	253.9	Spot melt	
Al-10Ag & Al-18Ag	282.5/282.5	0.1/0.1	Re-rasters with 100% overlap
	368.3/368.3	2/2	
	282.5	0.1	
	368.3	2	

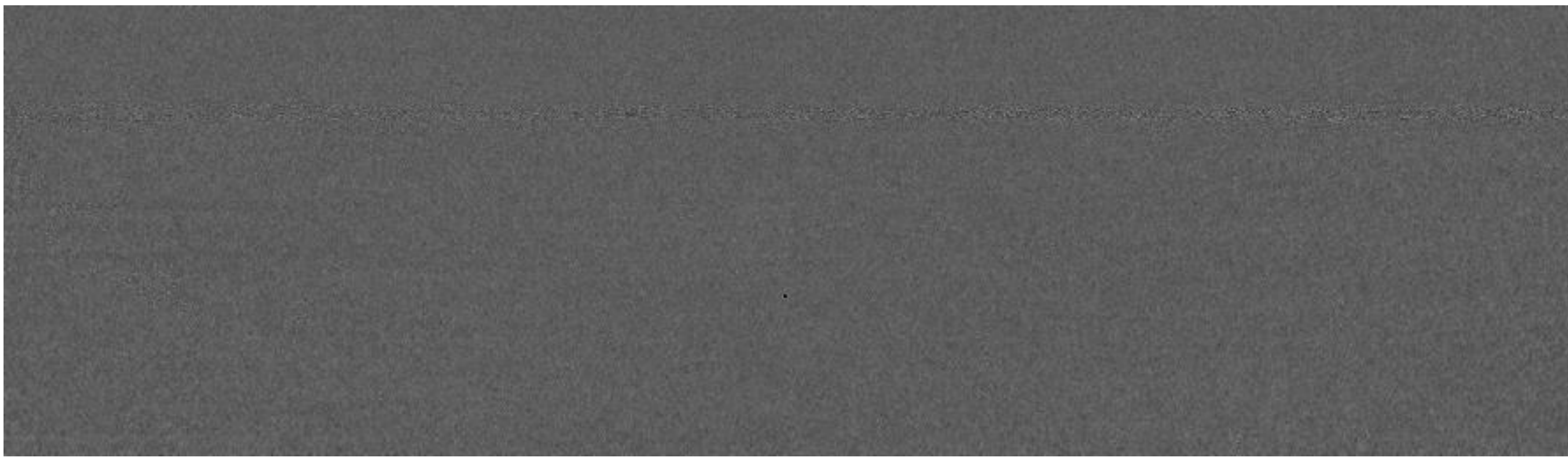
Spot Melt



High Power Spot Melt

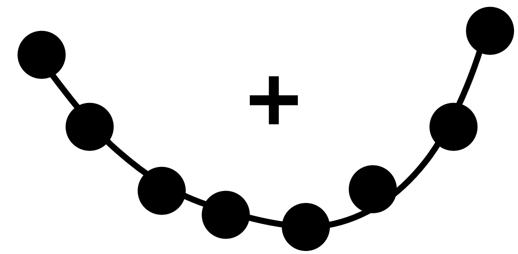


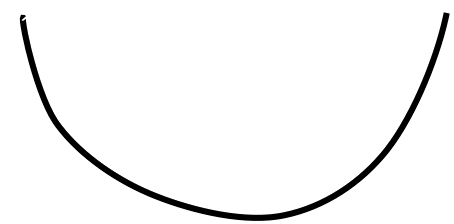
Raster

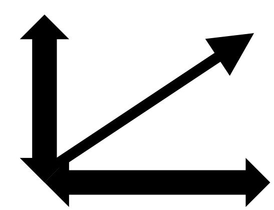


Recap of Previous Report

- Analysis of solid-liquid interface velocity based on melt pool shape
- Polynomial fit to manually found points
- Analyze change in position as polynomial function moves through a line
- Adjust magnitude to match known raster speed
- If needed for single crystals, compute projection of result onto unit vector of given angle matching dendrite angle

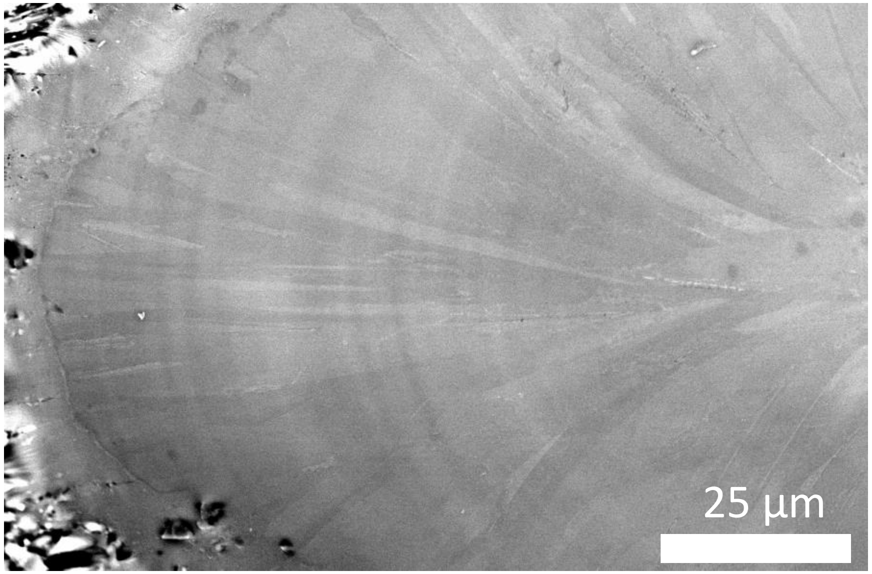




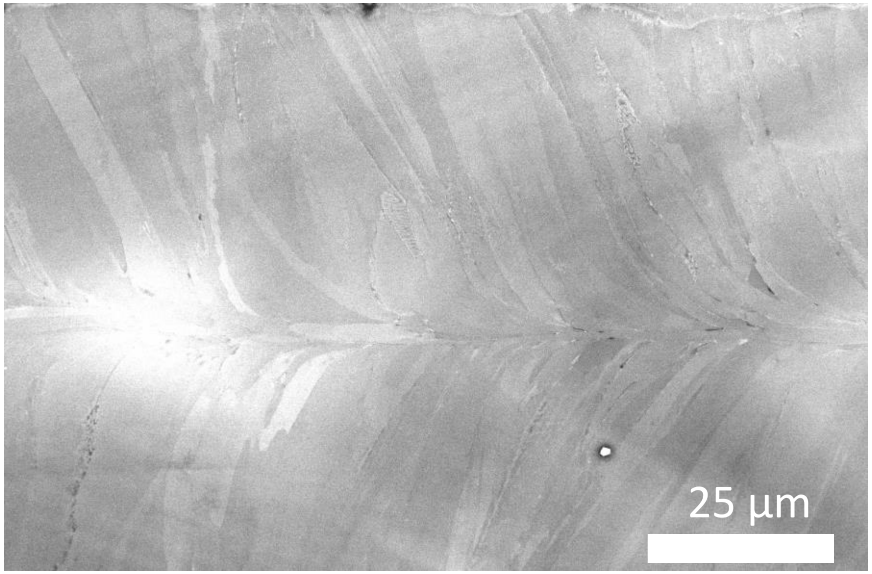


Conventional Columnar Grains in Al-Ag

- Under some conditions, Al-Ag samples develop long columnar grains following the heat source
- This is commonly observed in welds
- Angle changes as pool achieves steady state, also typical behavior



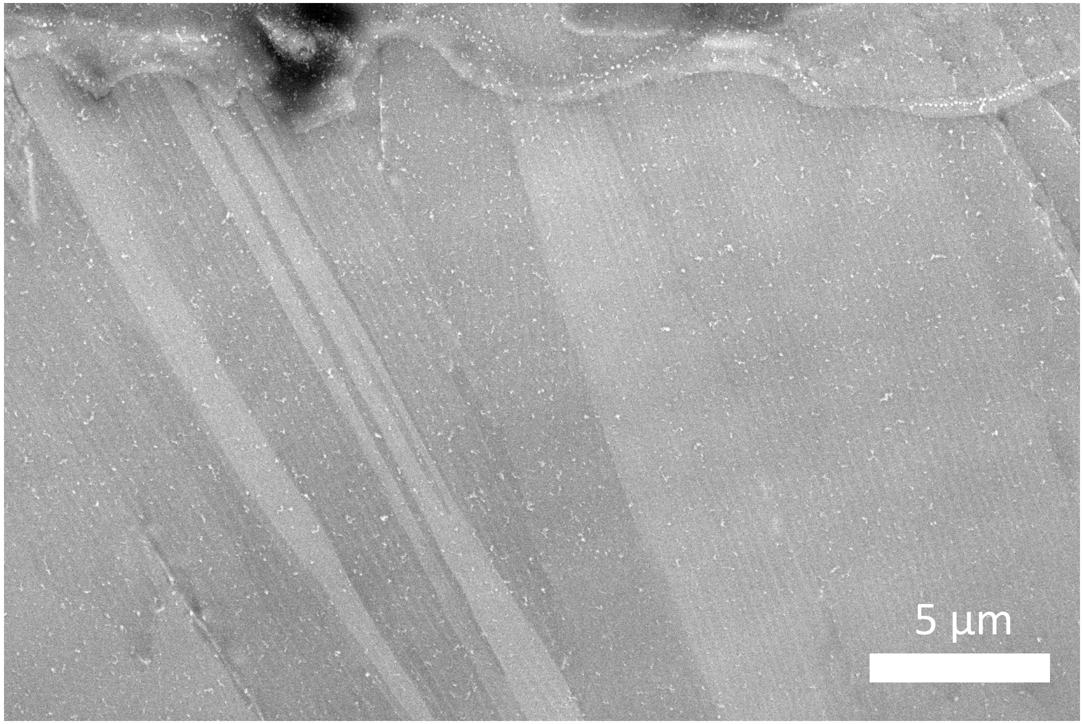
SEM, backscatter



SEM, backscatter

Silver Partitioning in Columnar Grains

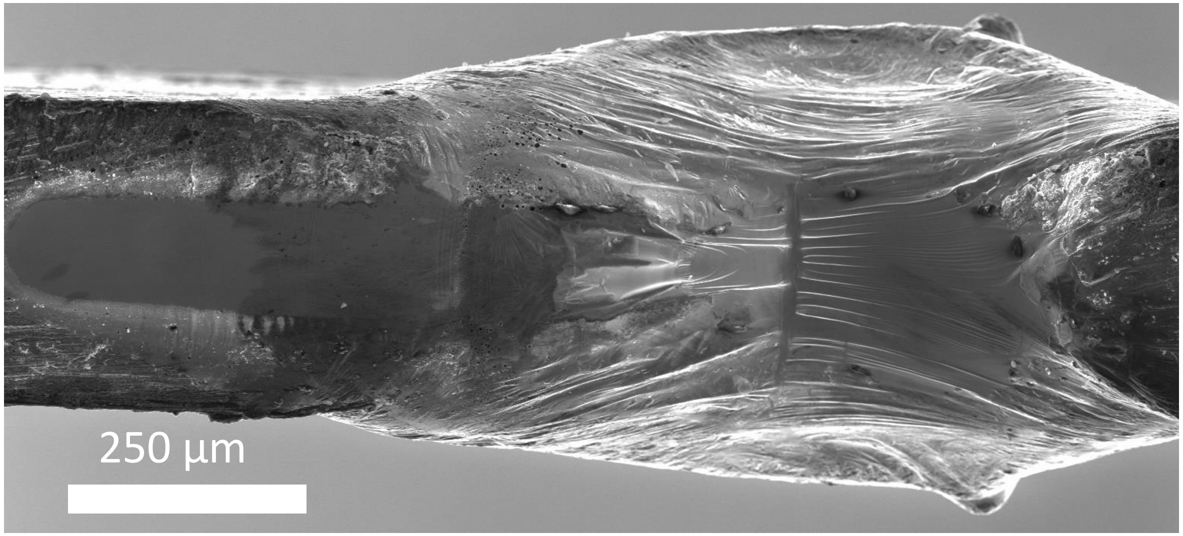
- Composition is not uniform within the columnar grains
- Silver partitions within the grains according to two different patterns seen thus far
- Straight lines and wavy lines of Ag partitioning



SEM, backscatter

Al-10Ag Re-Raster

- Re-rastered sample where both rasters transition from conduction mode to keyhole mode due to transient heat flow
- Region where solid-liquid interface was during transition displays several different microstructures



SEM, secondary electron

Microstructures in Transition Region

A – Columnar grains

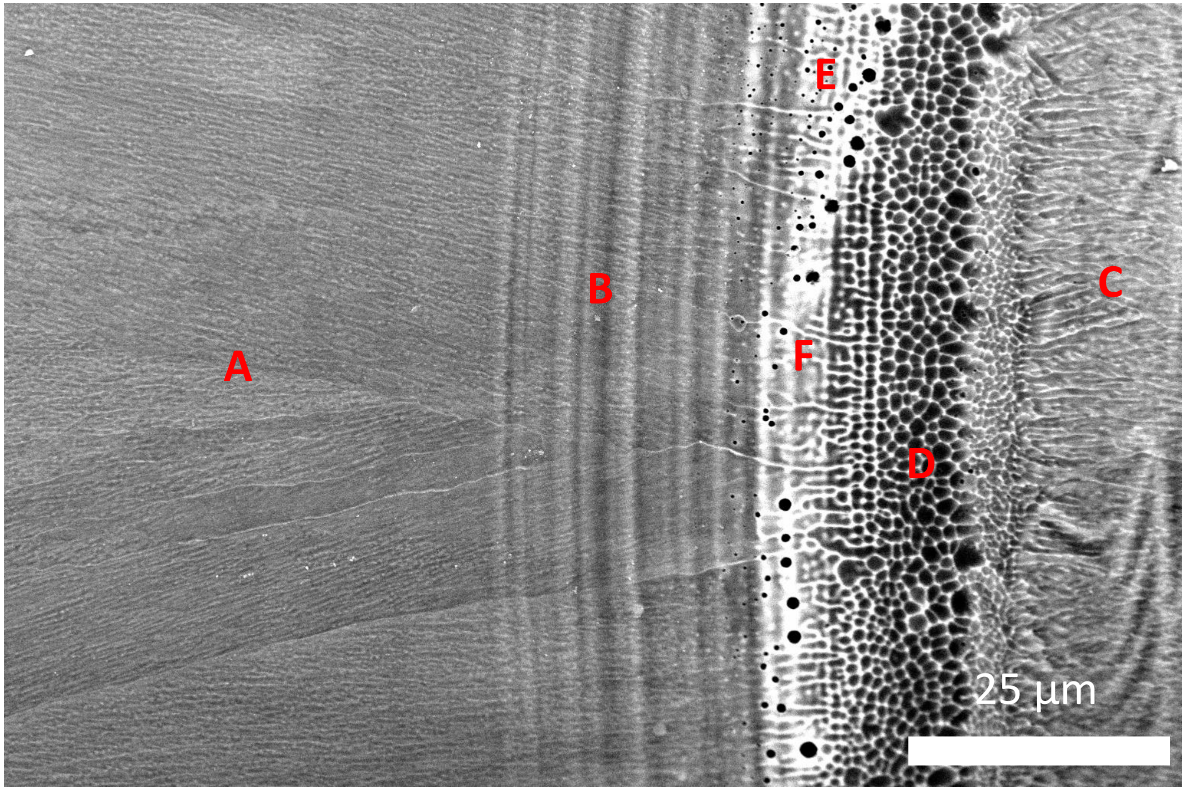
B – Ripples from fluid flow

C – Columnar grains with increased oxidation

D – Cellular

E – Pores

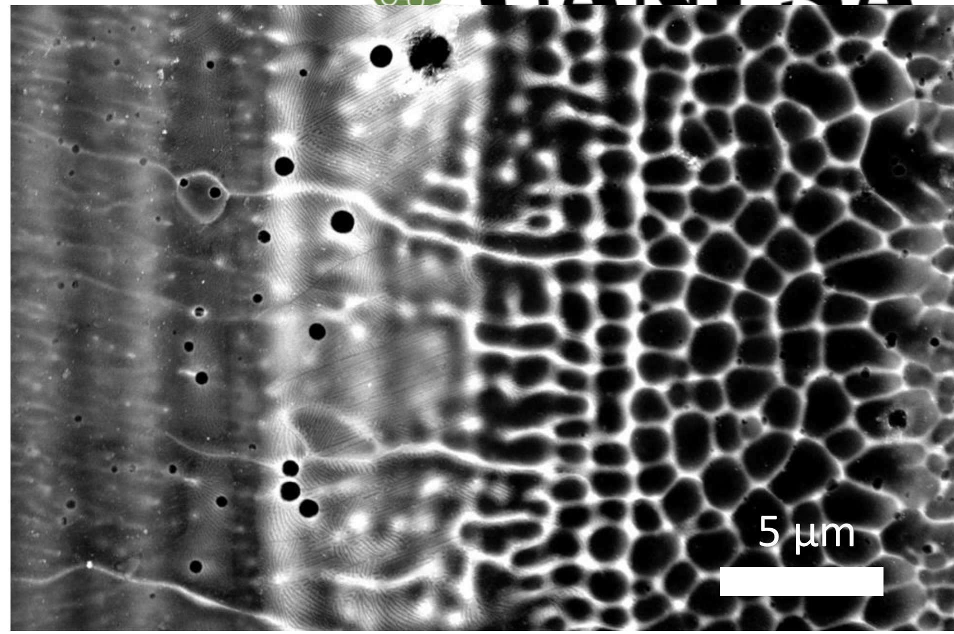
F – Shown next slide, only seen here (so far)



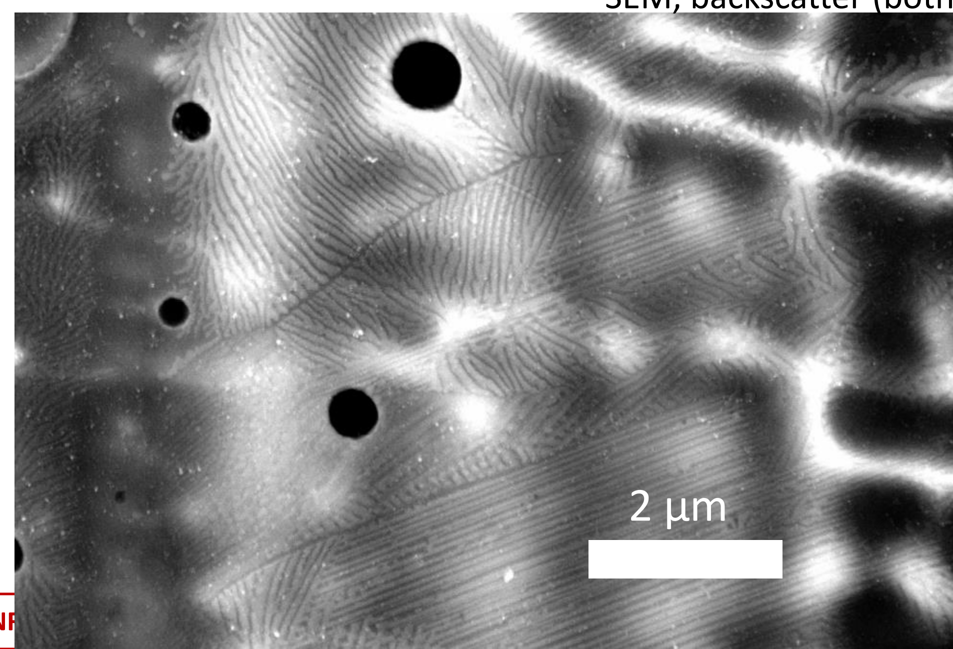
SEM, backscatter

Unique Microstructure in Al-10Ag Re-Raster

- Partitioning of Ag on two length scales simultaneously
- Ag rich lines continuous between columnar region, through this region, into cellular region
- Fine alternating layers of Ag and Al rich phases
- Seaweed like structures also apparent
- Similar features seen in DTEM

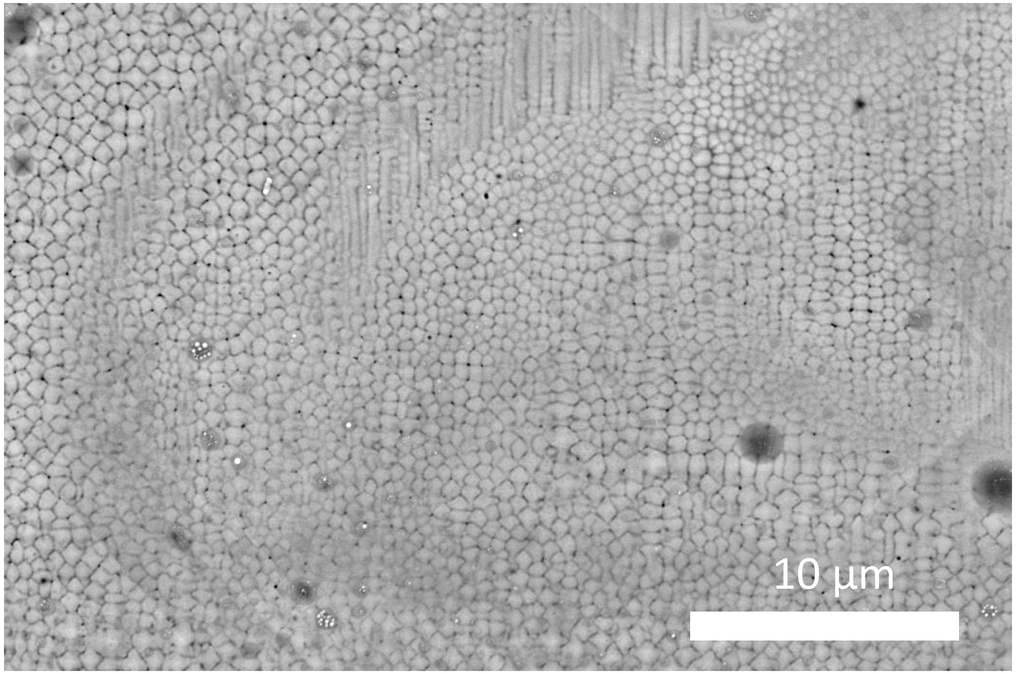


SEM, backscatter (both)



Dendritic Solidification in R4 <100> Oriented

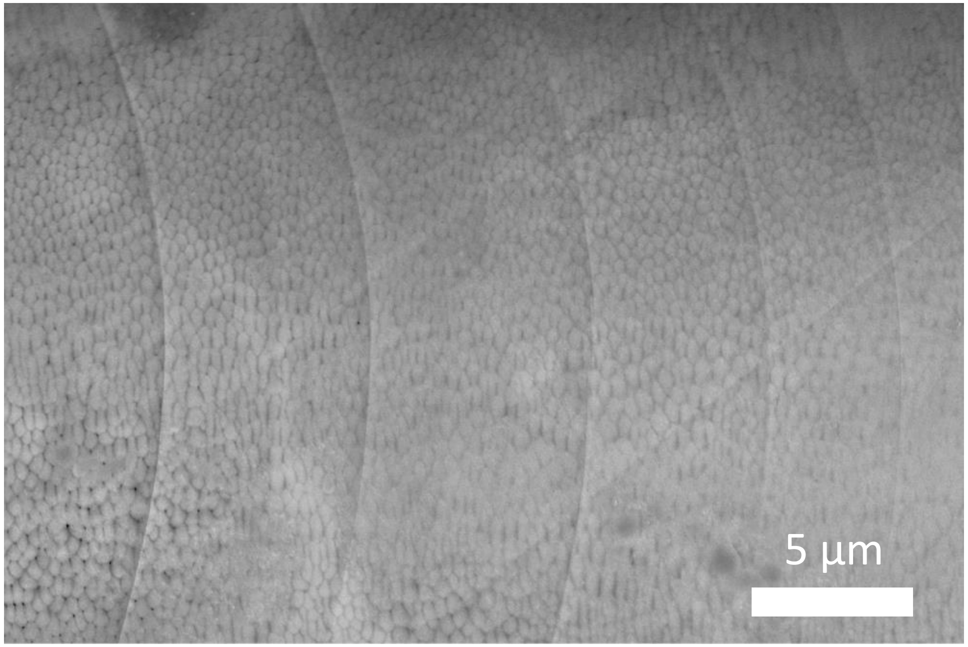
- The microstructure of many R4 melts can be readily identified as dendritic in nature
- Growth following crystallographic directions rather than maximum thermal gradient



SEM, backscatter

Some Regions Cannot be Confirmed Dendritic

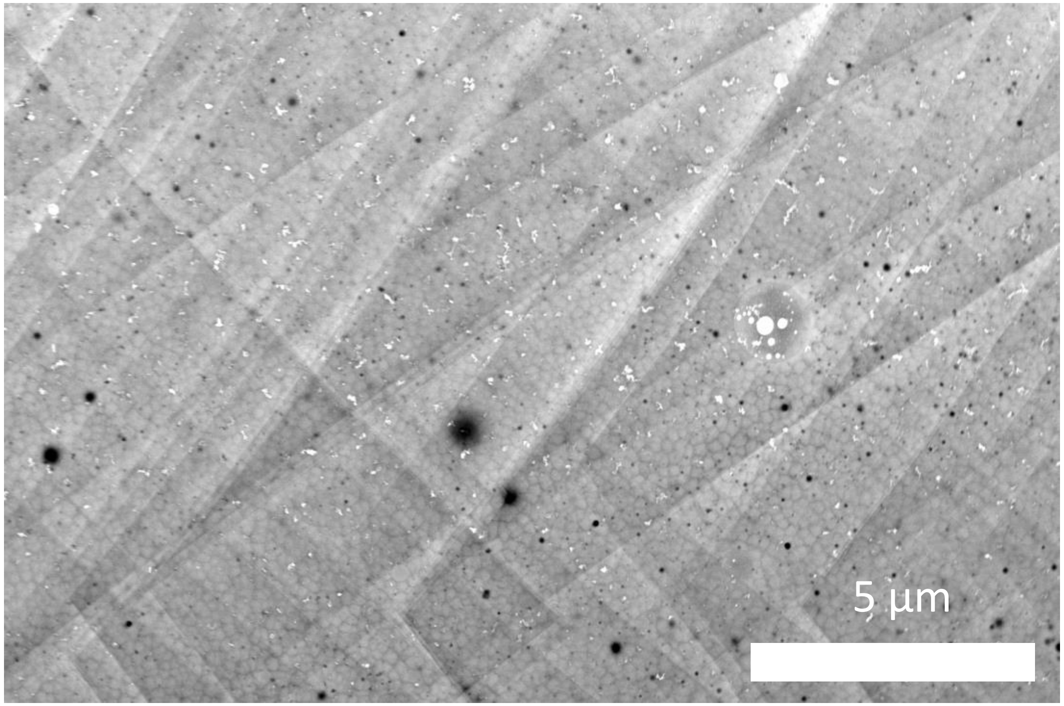
- Top-down imaging alone cannot confirm if this is dendritic or cellular
- Also a rare case of a region in R2 where the solidification structure can be readily distinguished



SEM, backscatter

Slip Lines may Confirm "Single Crystal" Dendritic Structure

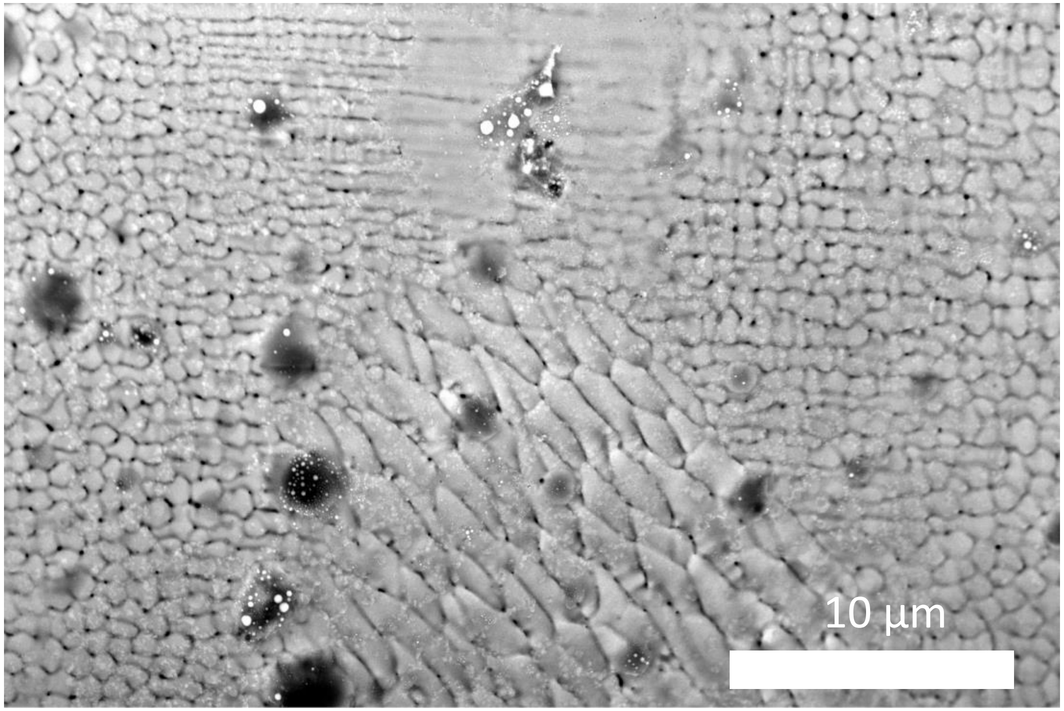
- Same ambiguous dendritic or cellular structure is present
- Lines are present in a pattern unlikely for fluid flow to have created, may be caused by dislocation movement



SEM, backscatter

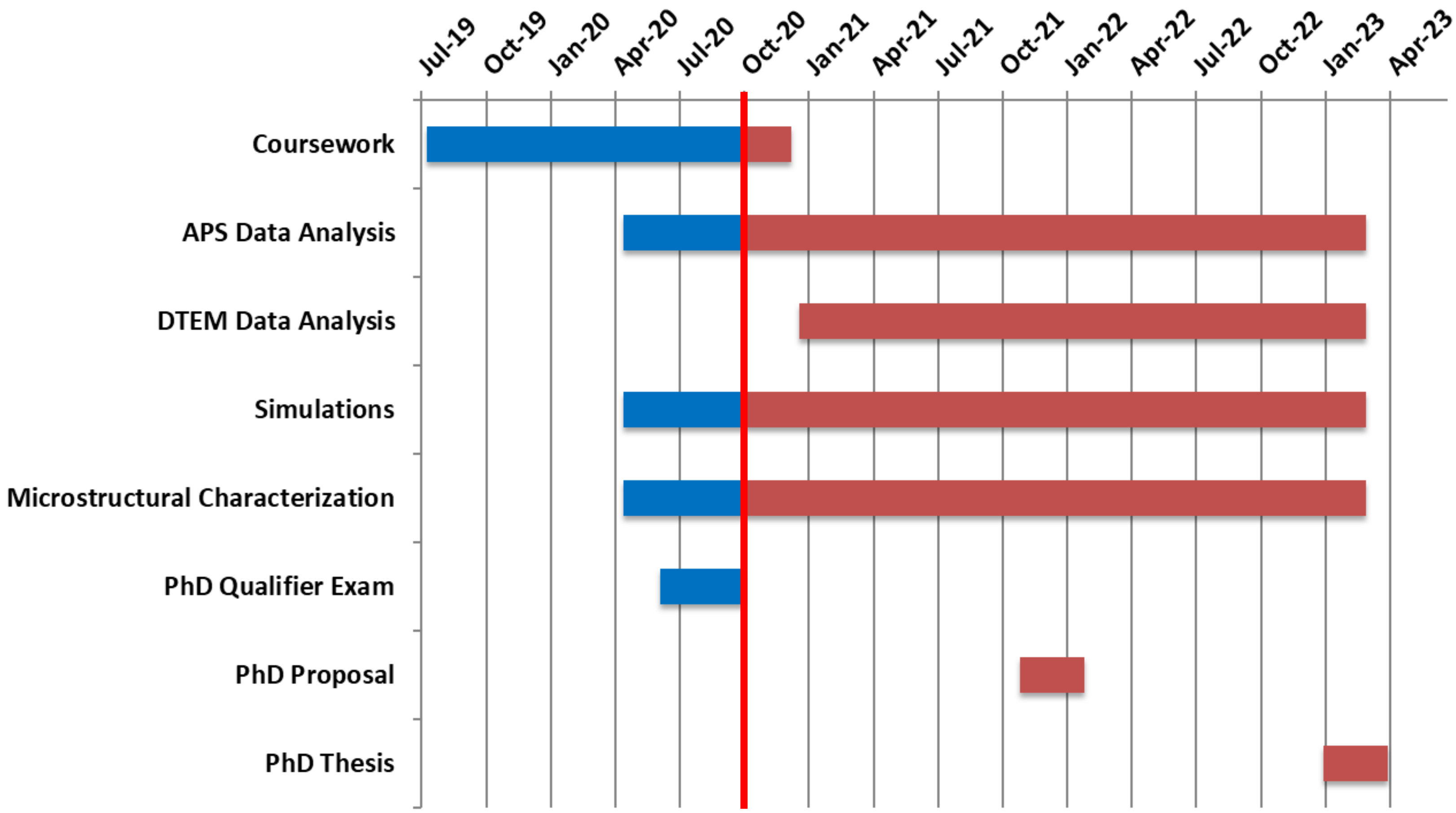
New Grain Orientations Nucleate in Spot Melts and Raster Starts

- New grain orientations only seen in these areas
- No new grain nucleation seen in steady state of rasters *so far*, not proof it has not occurred



SEM, backscatter

Progress



Jul-19
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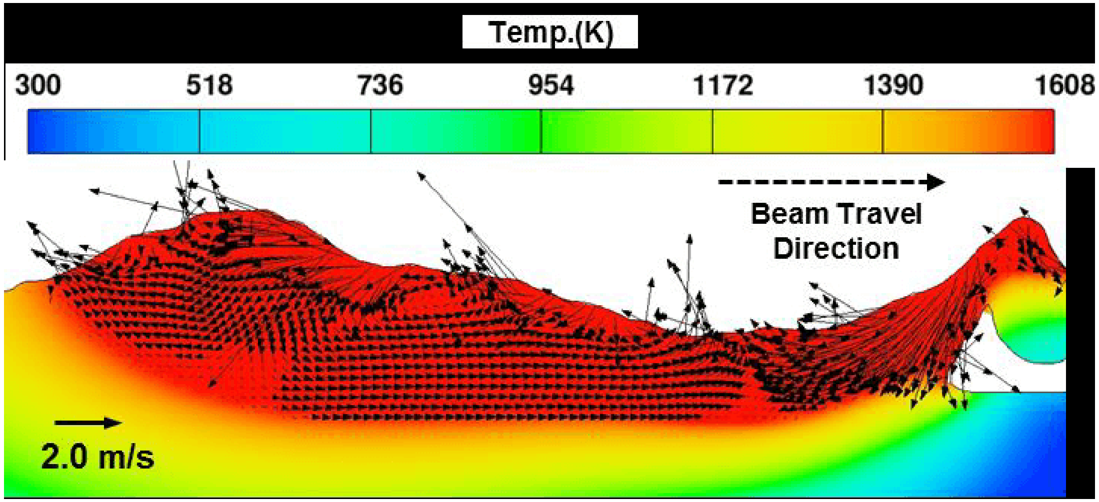
Jul-22
Oct-22
Jan-23
Apr-23
Coursework
APS Data Analysis
DTEM Data Analysis
Simulations
Microstructural Characterization
PhD Qualifier Exam
PhD Proposal
PhD Thesis

Challenges & Opportunities

- Microstructure analysis
  - Determining 3D structure, needing view from other angles
  - Identifying structure seen in Al-Ag

- FLOW-3D simulations
  - Learning software



Thank you!
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