Controlled Directional Solidification of Al-7 wt% Si in Microgravity: Overview and Early Results

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Outline

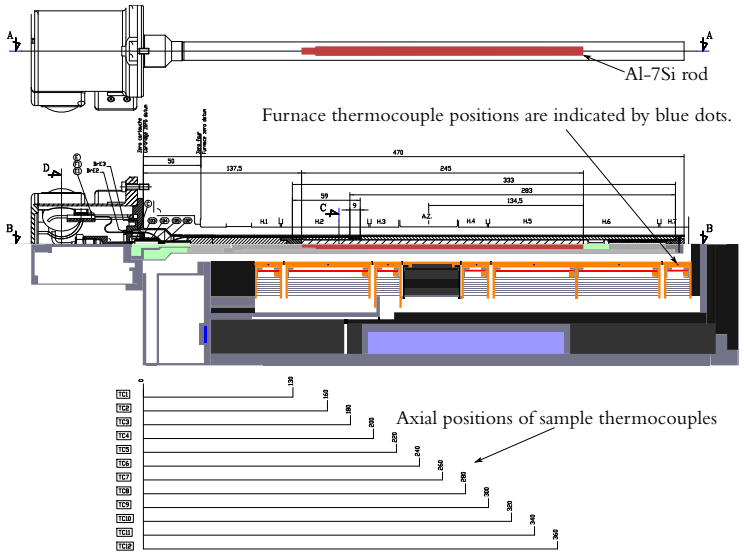
Experimental Apparatus

Materials Science Research Rack/Materials Science Laboratory (MSL/MSRR)

Sample Cartridge Assembly (SCA)

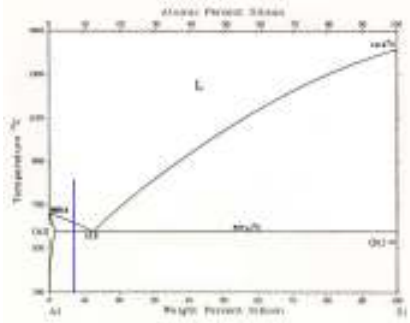
Low-Gradient Furnace (LGF) Insert

Furnace and Sample Cartridge Assembly



Overview of U.S. MICAST Experiments

- Two space samples:
  MICAST6 and MICAST7
- Directional solidification from monocrystalline seed
- Al-7 wt pct Si alloy (hypoeutectic)



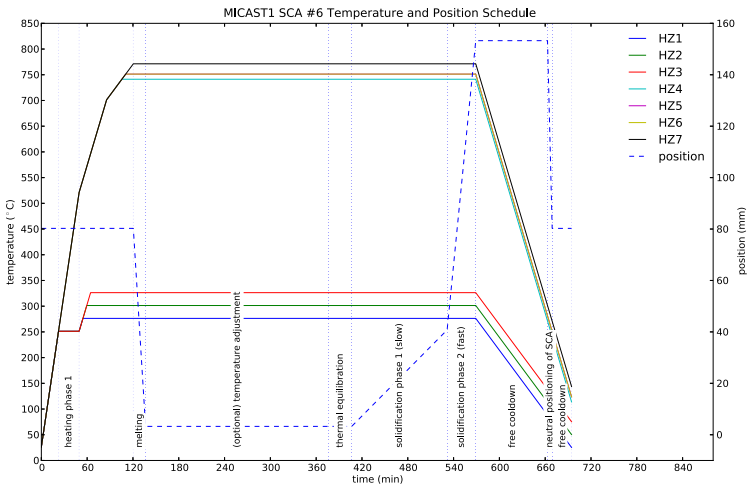
- Nominally **constant gradient** for each
- **Two solidification rates** in each
- **Matching terrestrial experiments** (Tewari)

Science Objectives

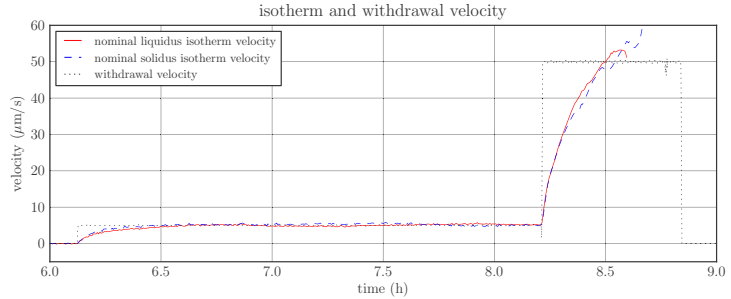
- Investigate influence of gravity on **dendrite placement and morphology**
  - Steady-state, fully-developed microstructure
  - PDAS, SDAS
  - Selection mechanisms in transitions
- Investigate influence of gravity on **macrosegregation**

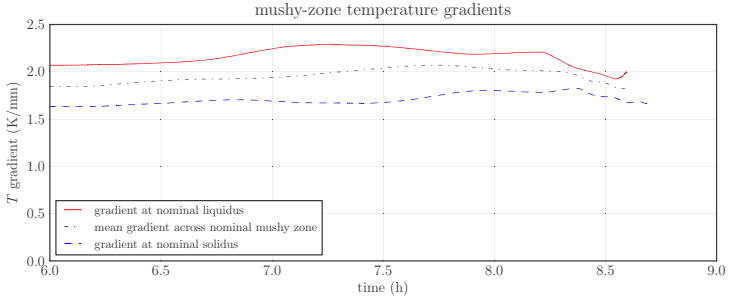
MICAST 6 and 7

- MICAST 6: slow (5 µm/s) then fast (50 µm/s)
- MICAST 7: fast (20 µm/s) then slow (10 µm/s)

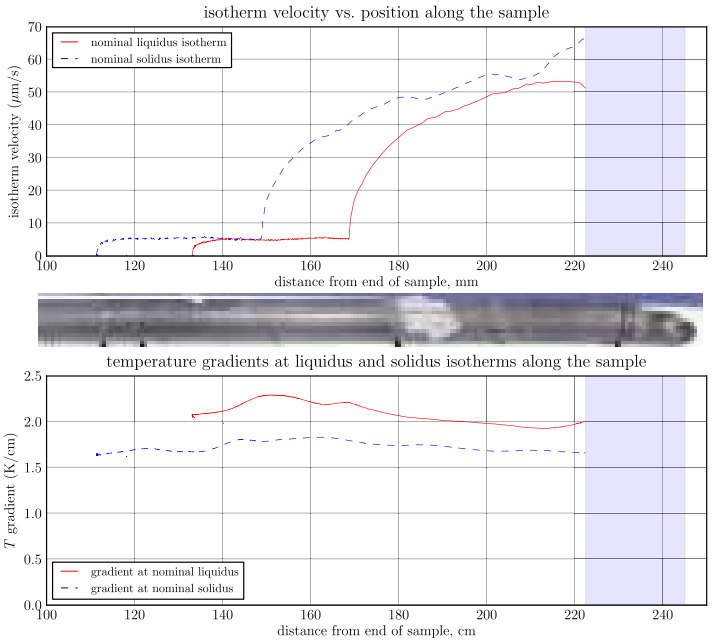


Sample 1: Solidification Conditions vs. Time

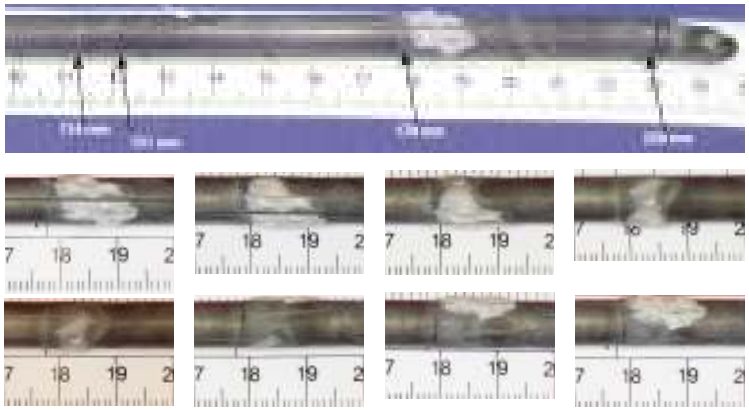




Sample 1: Conditions Along the Sample



Sample 1: Appearance After Crucible Removal



Sample 1: Microstructure Sample Locations

Transverse and longitudinal sections taken along full sample length.

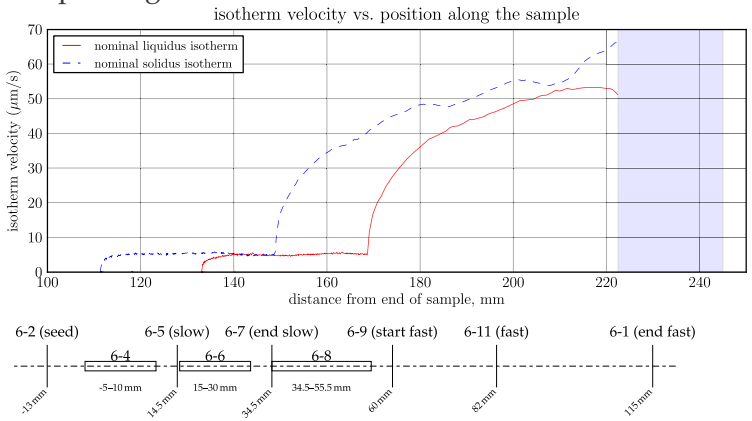
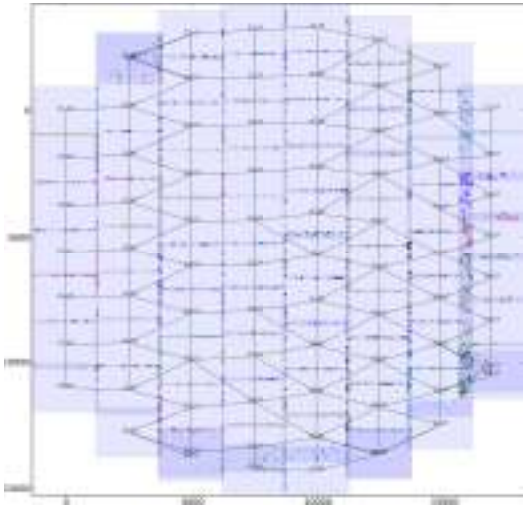


Image Analysis: Seamless Reconstruction

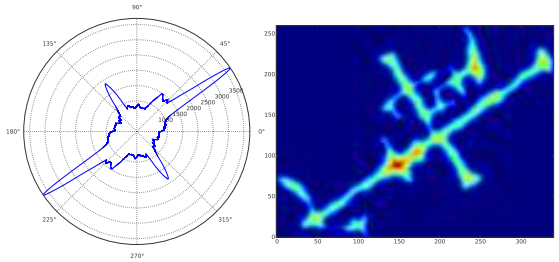


- Completely automated feature matching
- Automatic removal of non-uniform illumination
- Scale-space theory for multiscale blending
- No seams

New Microstructural Analysis Technique

Input:

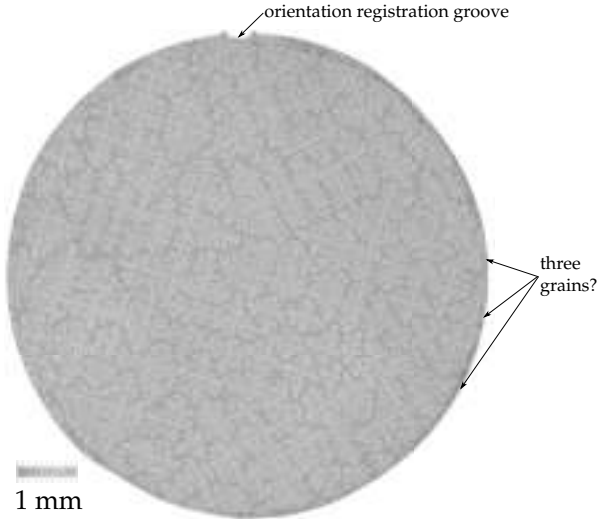
Output:



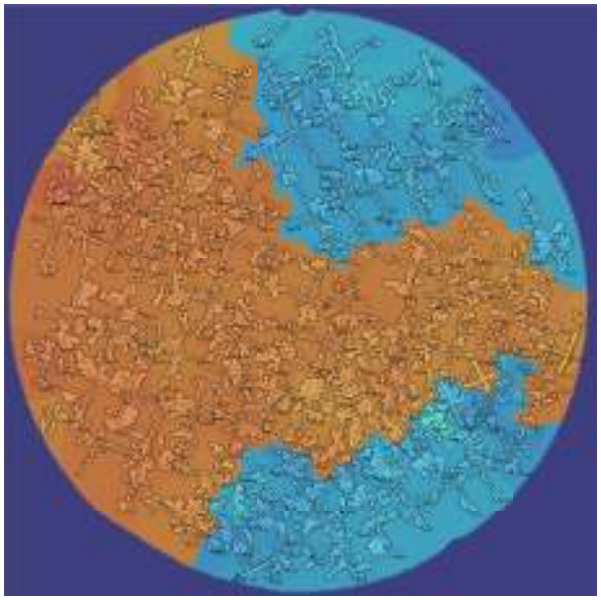
- Allows determination of cruciform orientation
- Applies to each cruciform
- Enables precise grain counting

Transverse Section M6-2: Terrestrial Seed Portion

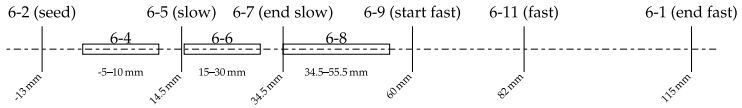
gradient $G = 40\,\mathrm{K/cm}$, velocity $R = 22\,\mu\mathrm{m/s}$

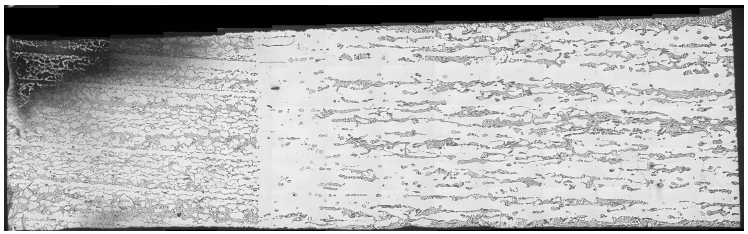


Transverse Section M6-2: Image Analysis



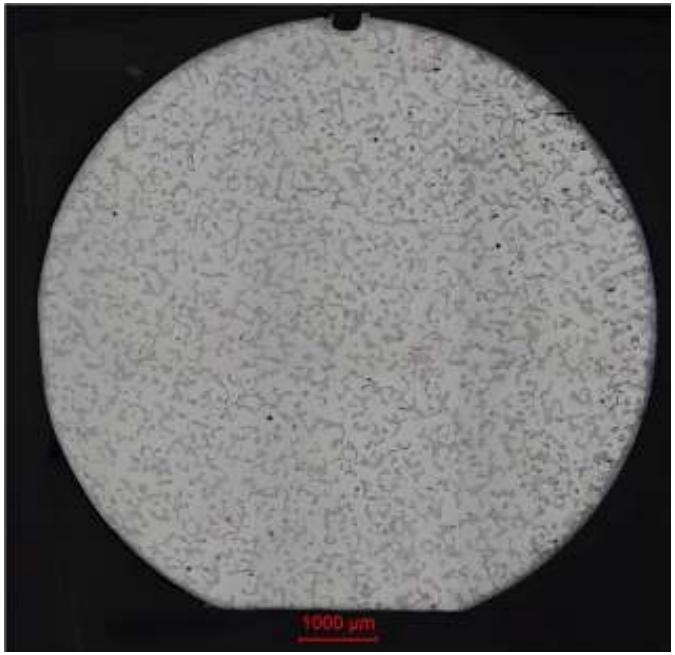
Longitudinal Section M6-4: Start



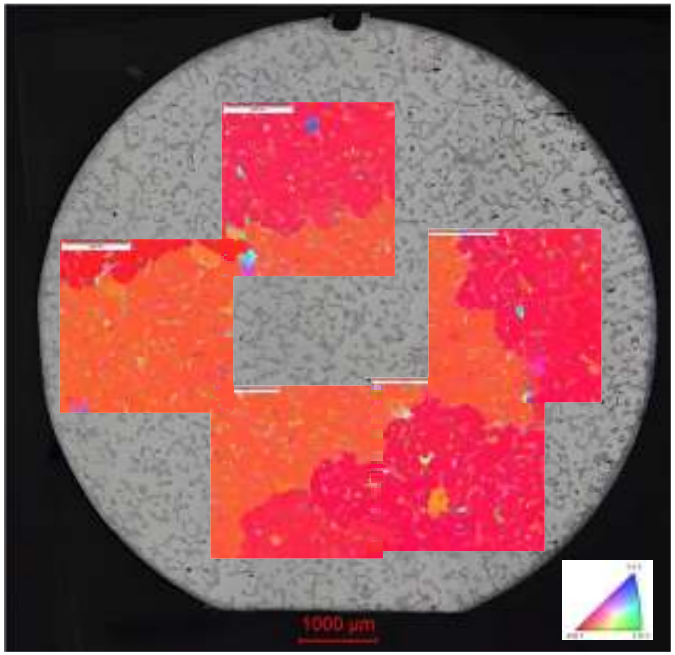


1 mm

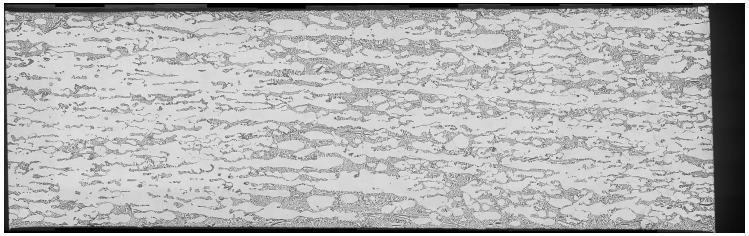
Transverse M6-5: Initial Mushy Zone



Transverse M6-5: EBSD

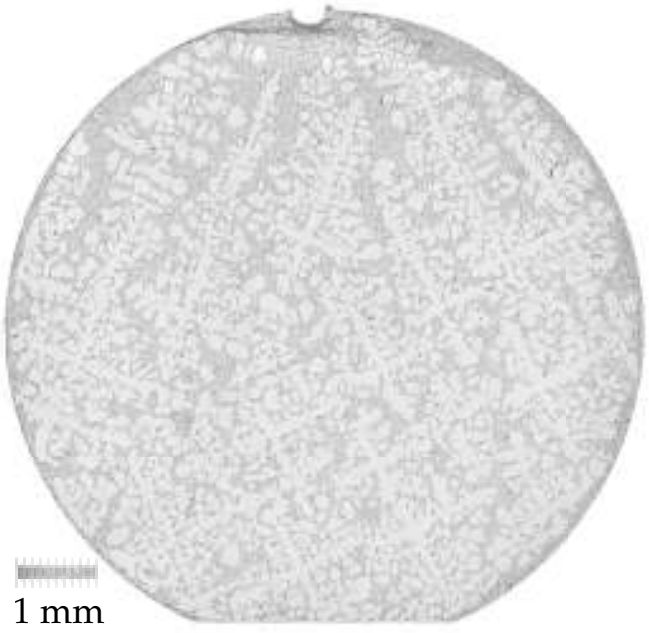


Longitudinal Section M6-6: Slow (5 µm/s)

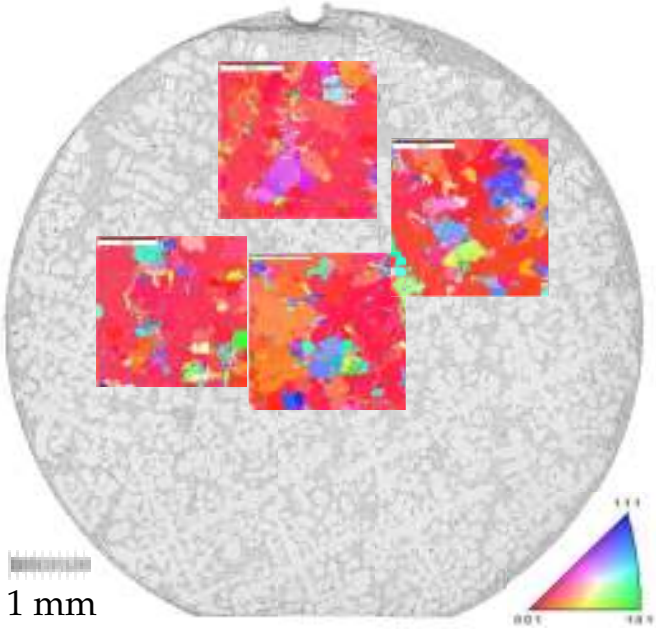


1 mm

Transverse M6-7: End of Slow

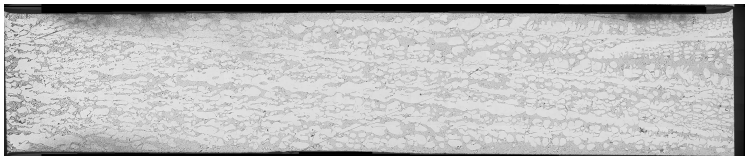


Transverse M6-7: EBSD



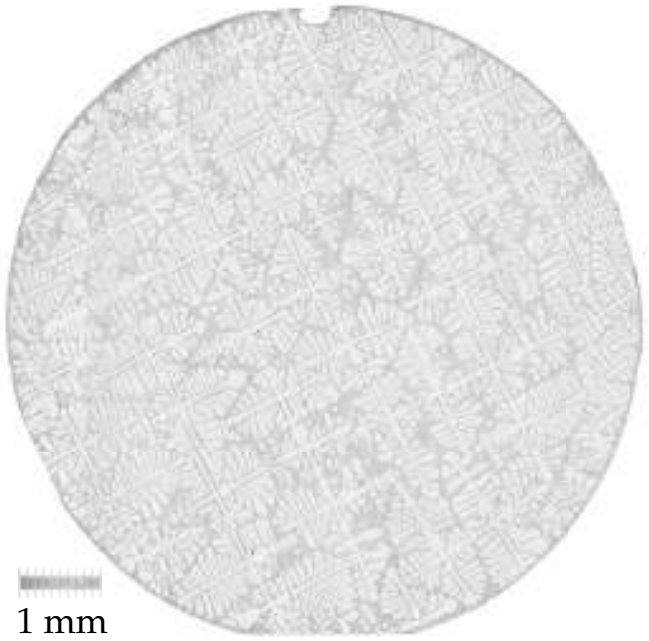
Transverse M6-7: Image Analysis

Longitudinal Section M6-8: Transition (5–50 µm/s)

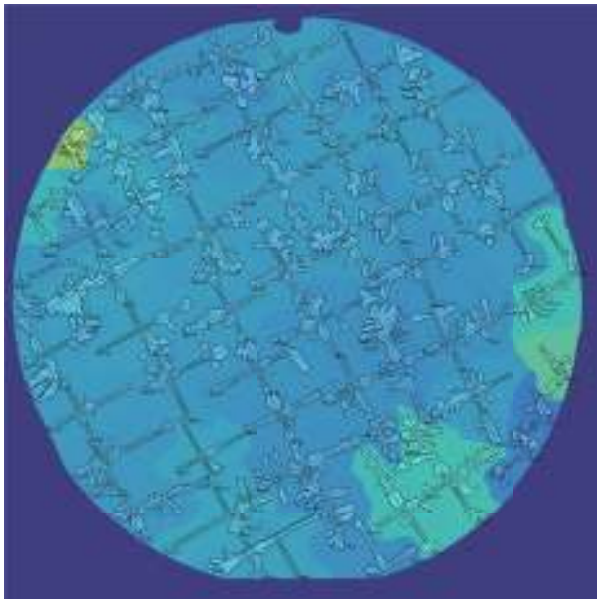


1 mm

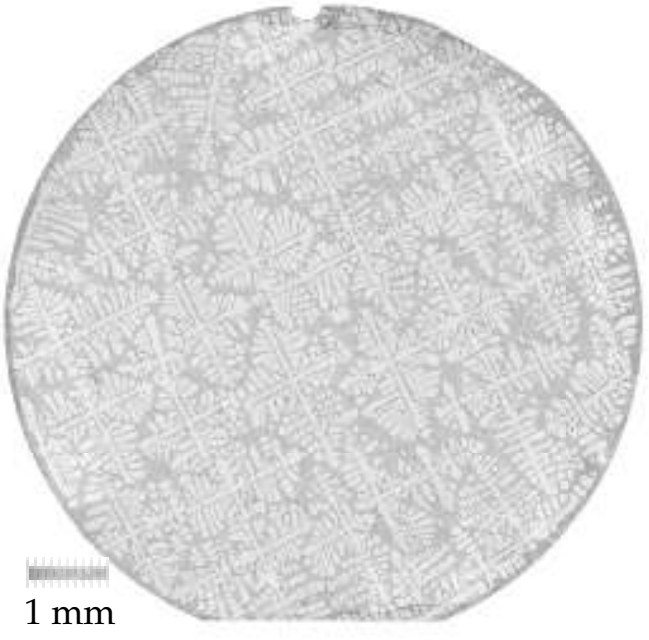
Transverse M6-9: Start of Fast



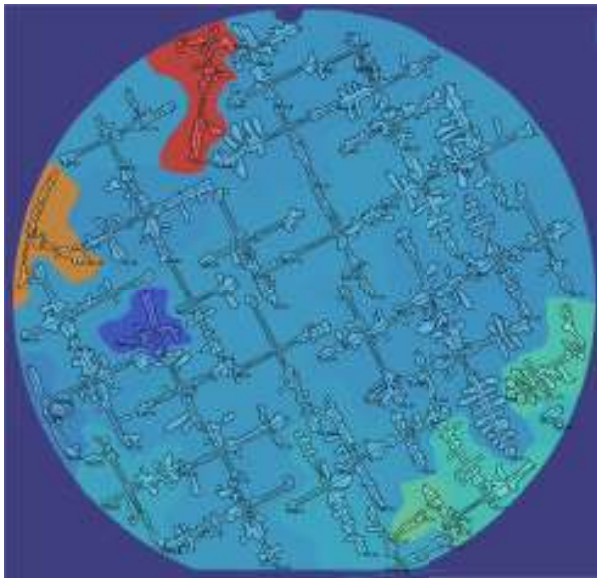
Transverse M6-9: Image Analysis



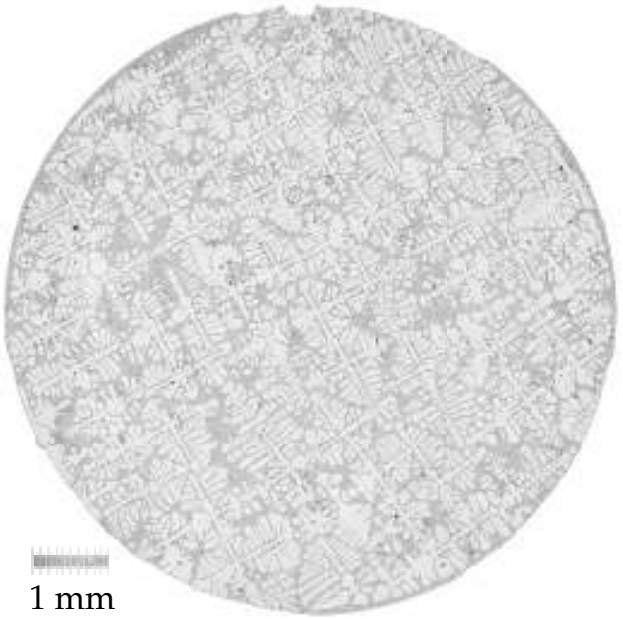
Transverse M6-11: Middle of Fast



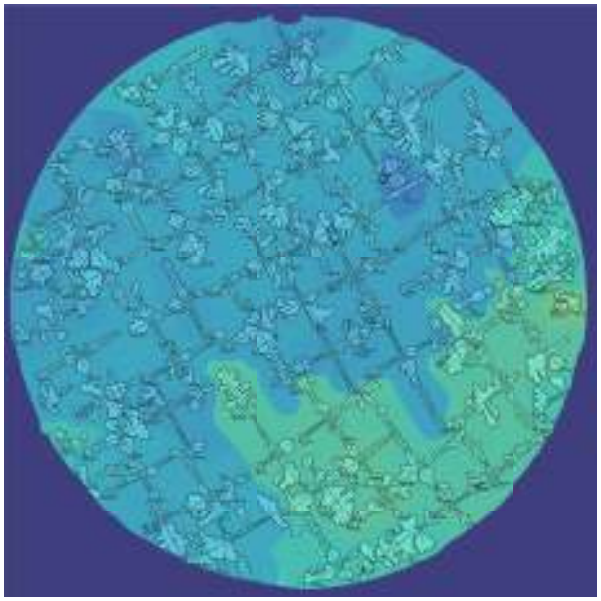
Transverse M6-11: Image Analysis



Transverse M6-1: End of Fast

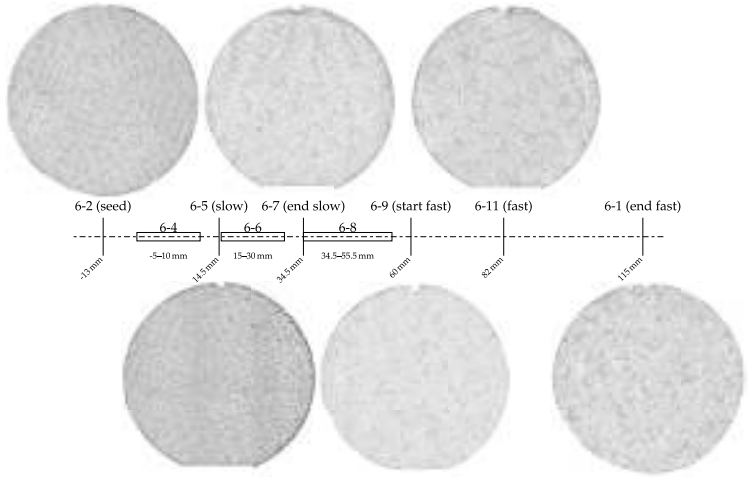


Transverse M6-1: Image Analysis



Survey of Transverse Sections

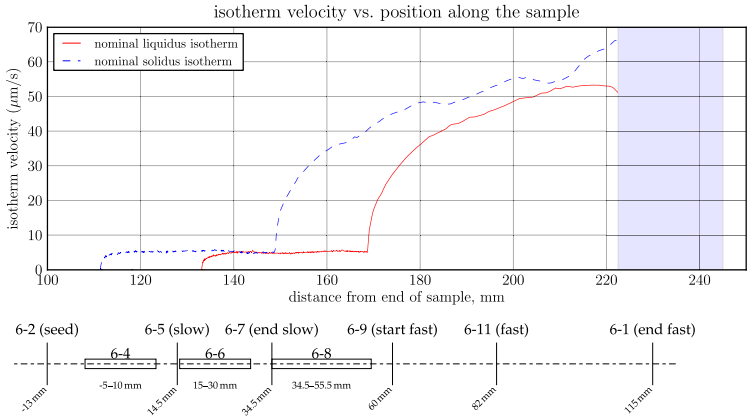
From seed through slow growth, transition, fast growth.



Evolution of Grains

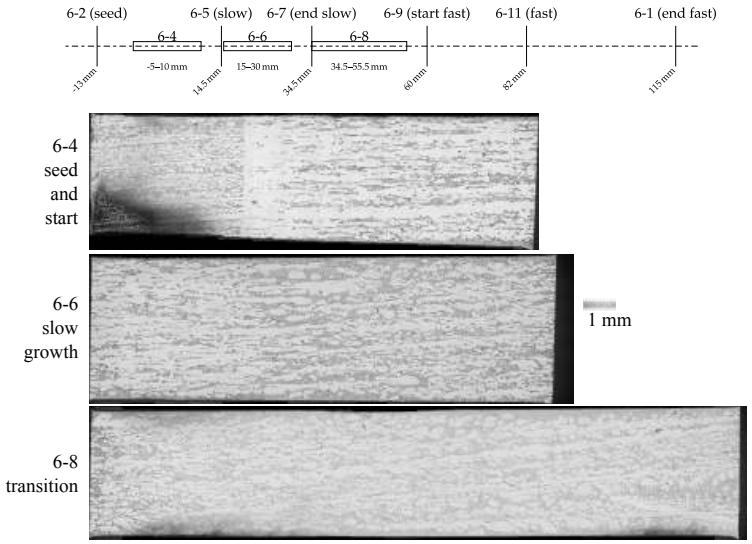
From seed through slow growth, transition, fast growth.

High-resolution Longitudinal Sections



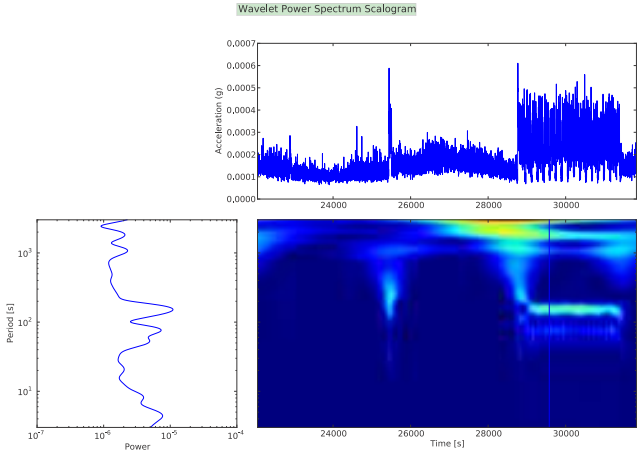
Survey of Longitudinal Sections

From seed through slow growth, transition to fast growth.



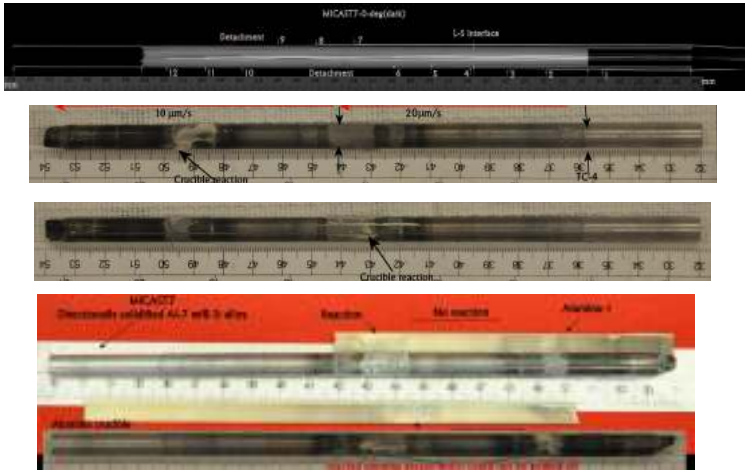
Accelerations

- Experiment performed during crew sleep.
- Sample held fixed, furnace is moved.
- Minimal acceleration is critical.
- Anomalous accelerations encountered.



Sample 2 (M7): Appearance After Crucible Removal

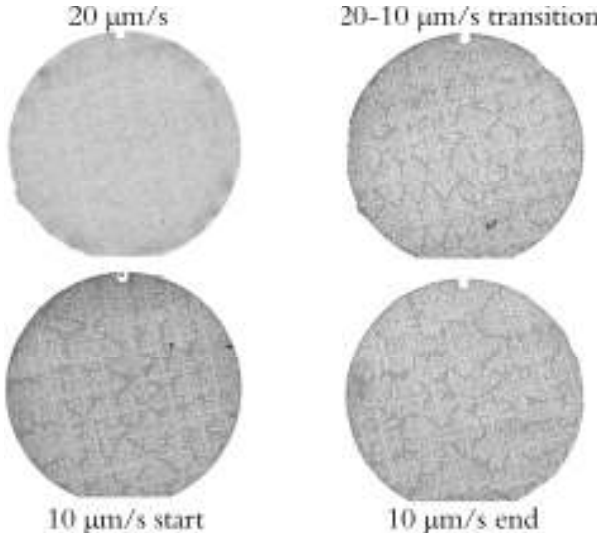
- Evidence of metal-crucible reactions.
- Evidence of metal free surface due to non-wetting.



Early Survey of Transverse Sections

gradient $G = 28$–$30\,\mathrm{K/cm}$

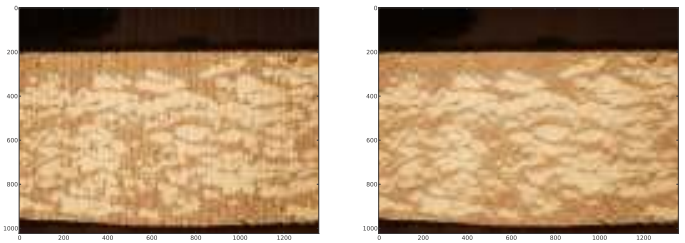
From fast growth through transition to slow growth.



Micromilling for 3-D Reconstruction

- Micromilling
- 5 micron spacing
- optical microscopy at high magnification
- Stacked to obtain 3-D structure
- Will be used for longitudinal (shown) and transverse sections

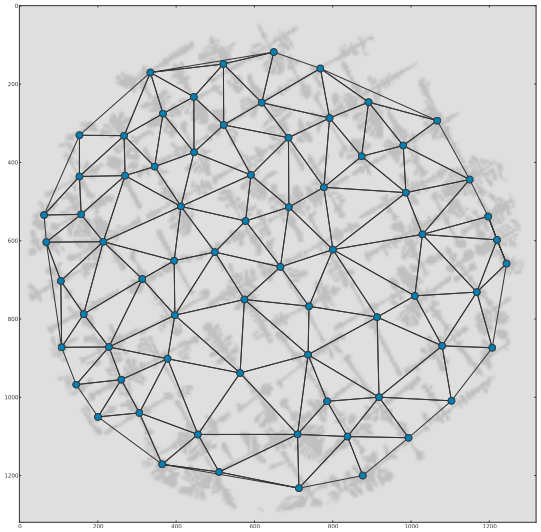
New Image Analysis Technique



- For reconstructing 3-D structures
  need high-quality images
- Micromilling causes severe artifacts
- Developed new hybrid wavelet-FFT identification and **removal of machining scratches**.
- Still in active development

Future: Spacing/Regularity Analysis

- Voronoi diagram of cruciform centers of mass



Future Analysis

- Micromilling of most of the sample in alternating transverse and longitudinal orientations.
- 3D reconstruction of microstructure
- Complete characterization of dendrite geometry
  - Usual average PDAS based on number per unit area
  - Histograms based on distances to centers of all other dendrites (1st neighbor distance, 2nd neighbor distance, etc.)
- Characterization and modeling of segregation

Summary

- Analysis of both ISS samples is progressing
- Matching terrestrial experiments done
- Several new image-processing techniques developed to gain maximum value from samples

Acknowledgements

- Ouliana Panova, UA
- NASA
- ESA
- DLR-MUSC
- EADS-Astrium

Thank you for your attention