Modeling The Effect of Gravity on Macrosegregation during Directional Solidification

Alexander Miles
Advisor: Dr. Robert Erdmann

Department of Materials Science
College of Engineering
University of Arizona

April 12, 2010

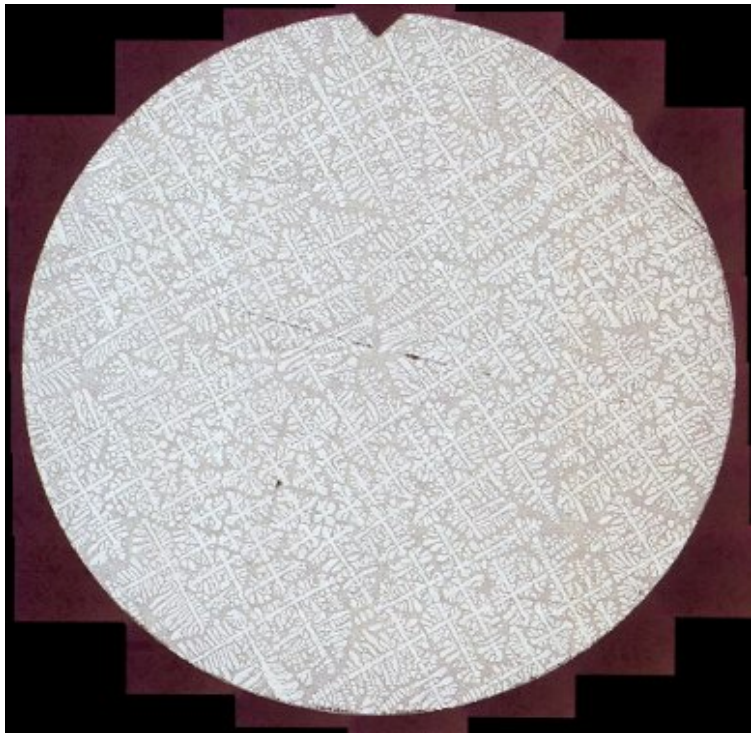
Background
Terrestrial
Space Based
Methods
Results
Summary
Future Work
Acknowledgements

Goals of Space Grant Project

- Model solidification experiments of Dr. Poirier and Dr. Erdmann on the ISS
- Predict degree of macrosegregation in space-based experiments
  - Thermosolutal convection:
    Temperature differences $\Rightarrow$ Density differences
  - Lighter liquid rises up, but in space there is no "up"
- Validate model for solidification in absence of gravity

Terrestrial Experiments

- Carried out at Cleveland State University
- Experiments run in normal gravity
- Chemical analysis used to test composition
- Data used to validate model



Dendrite microstructure from terrestrial experiment, courtesy of Surendra Tewari of CSU

Space Based Experiments

- No gravity therefore no thermosolutal convection
- Directionally solidified
- Carefully isolated from vibration
- Two experiments

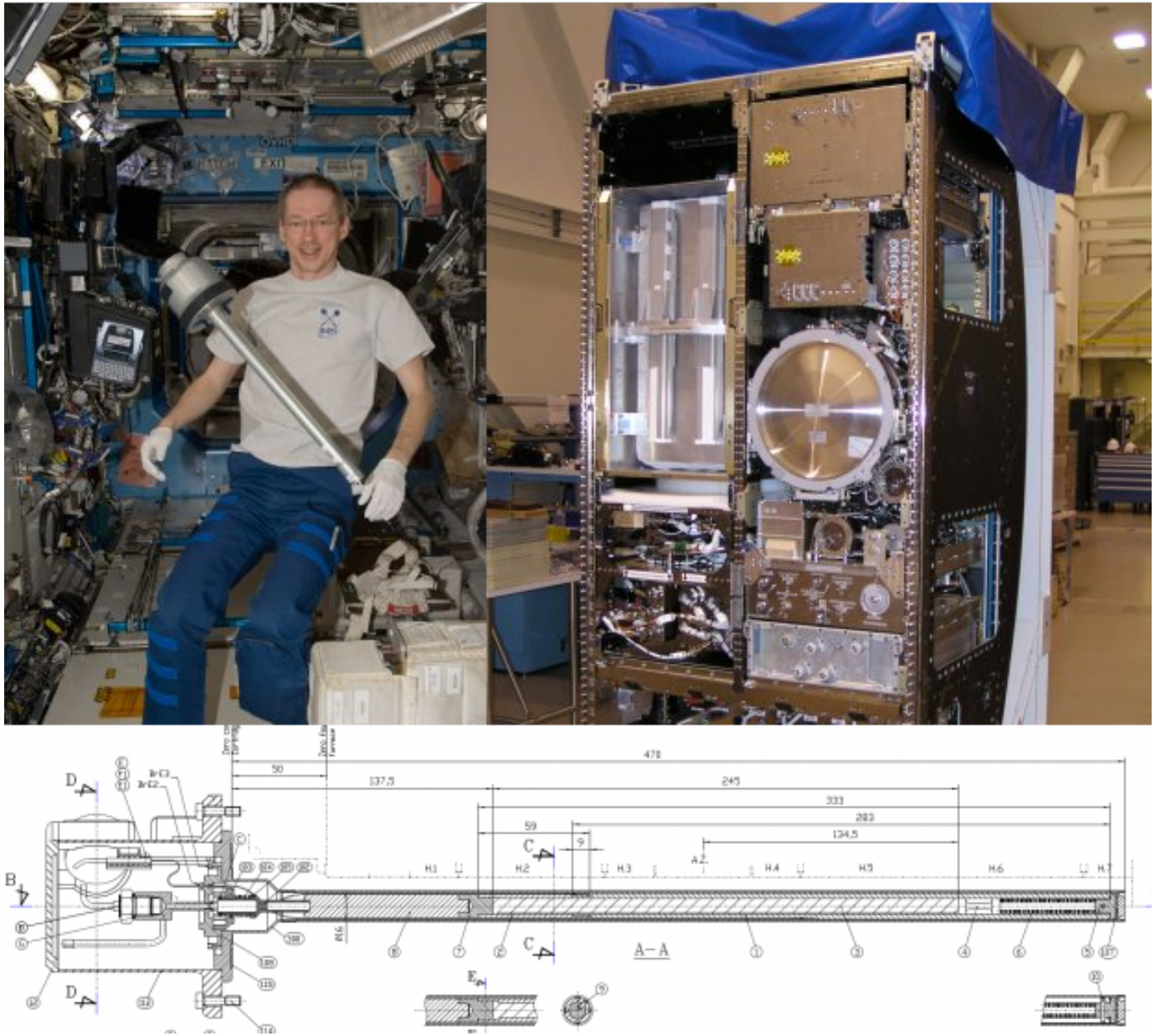
The International Space Station, photo courtesy of NASA

Why do we care?

- Processing dictates composition and structure
- Composition and structure dictate properties
- Composition and structure depend on convection
- Thermosolutal convection requires gravity

A freckle defect in solidified metal

Solidification Cartridge Assembly (SCA)

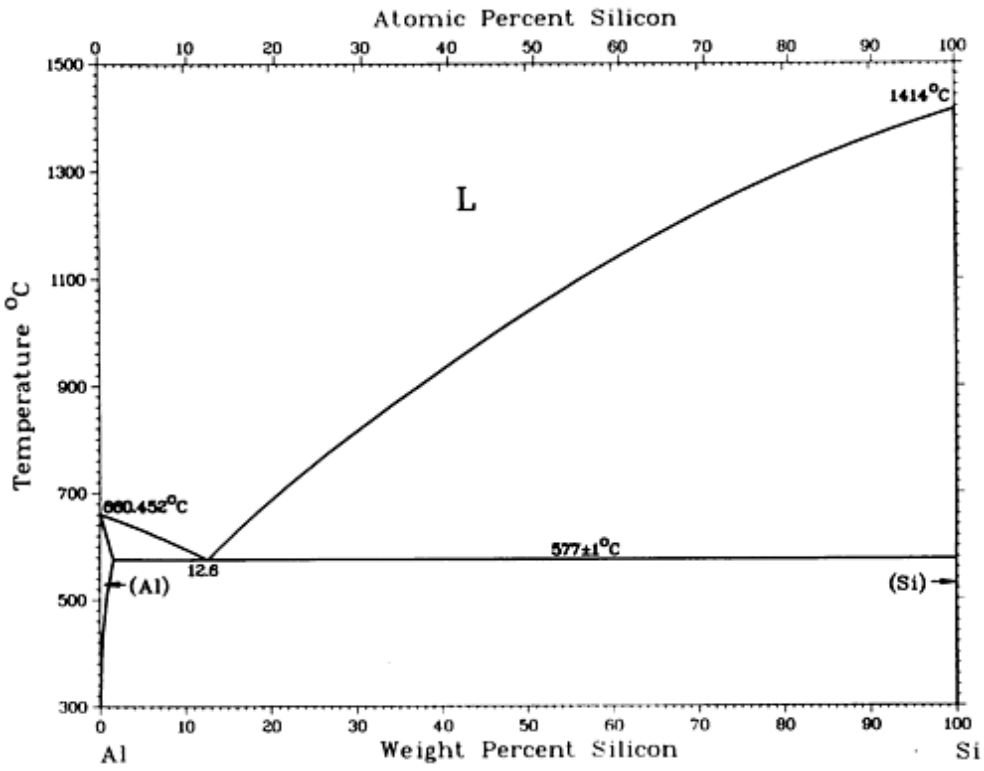


Photos courtesy of NASA

Simulation

Model solves for:

- Temperature
- Fraction solid
- Velocity
- Composition of the solid
- Composition of the liquid



J.L. Murray and A.J. McAlister, 1984

Modeling The Effect of Gravity on Macrosegregation during Directional Solidification

Alexander Miles
Advisor: Dr. Robert Erdmann

Background
Terrestrial
Space Based
Methods
Results
Summary
Future Work
Acknowledgements

Boundary and Initial Conditions

- The bottom of the bar was cooled at a constant rate (Dirichelt)
- The top of the bar was held to have a constant temperature gradient (Neumann)
- Initially imposed temperature gradient across the bar

$$\frac{\partial T}{\partial y} = C$$

$$\frac{\partial T}{\partial x} = 0 \qquad \frac{\partial T}{\partial x} = 0$$

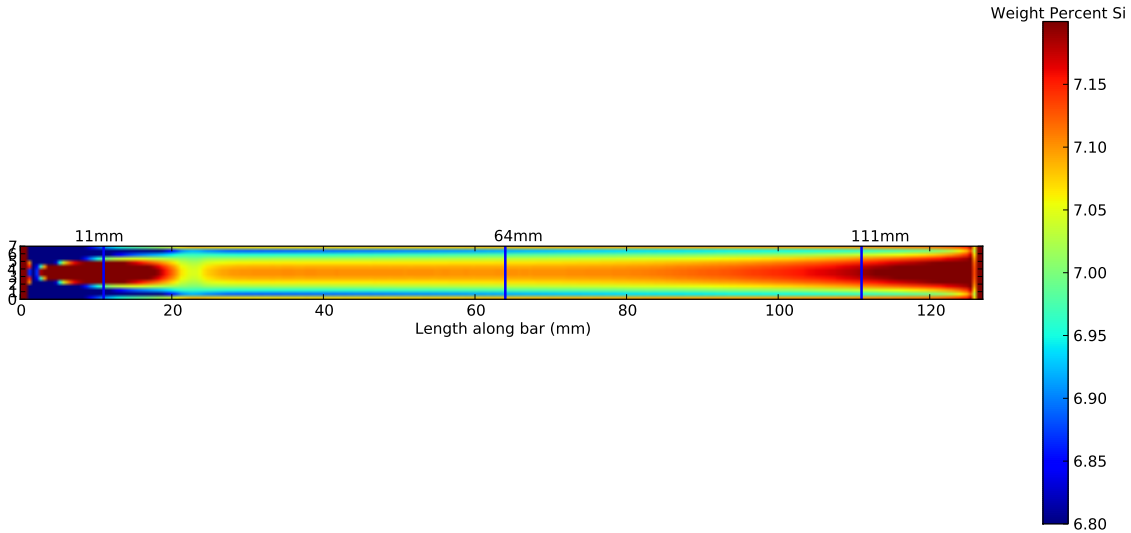
$$T = T_0 - \epsilon\, t$$

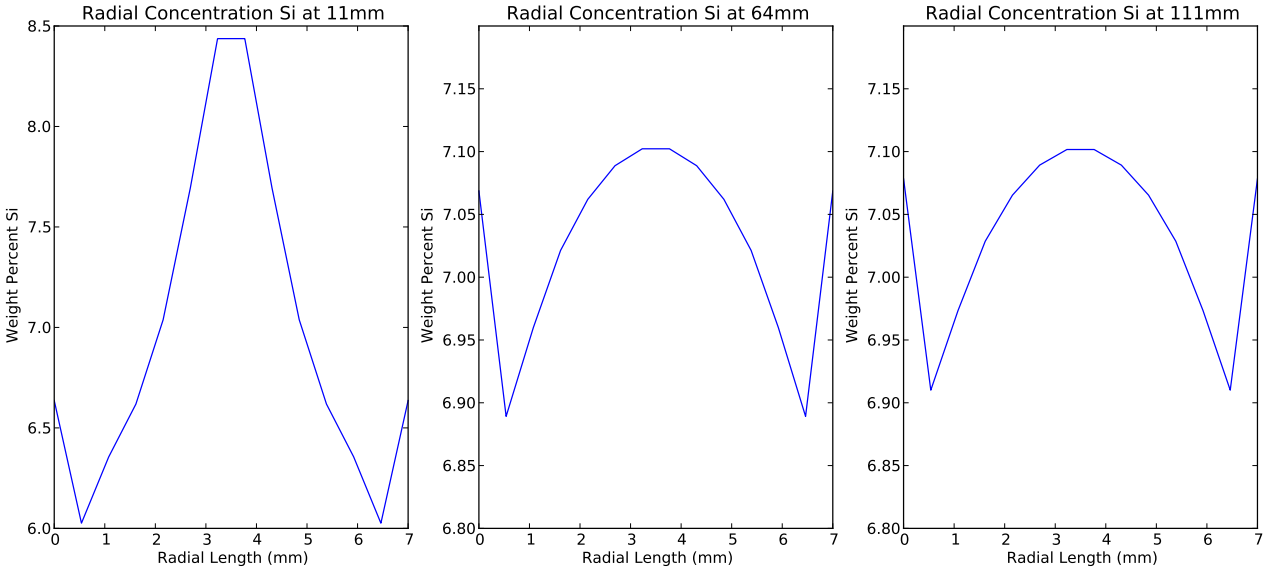
Modeling The Effect of Gravity on Macrosegregation during Directional Solidification

Alexander Miles
Advisor:
Dr. Robert Erdmann

Background
Terrestrial
Space Based
Methods
Results
Summary
Future Work
Acknowledgements

Results - With Gravity, Slow Cooling



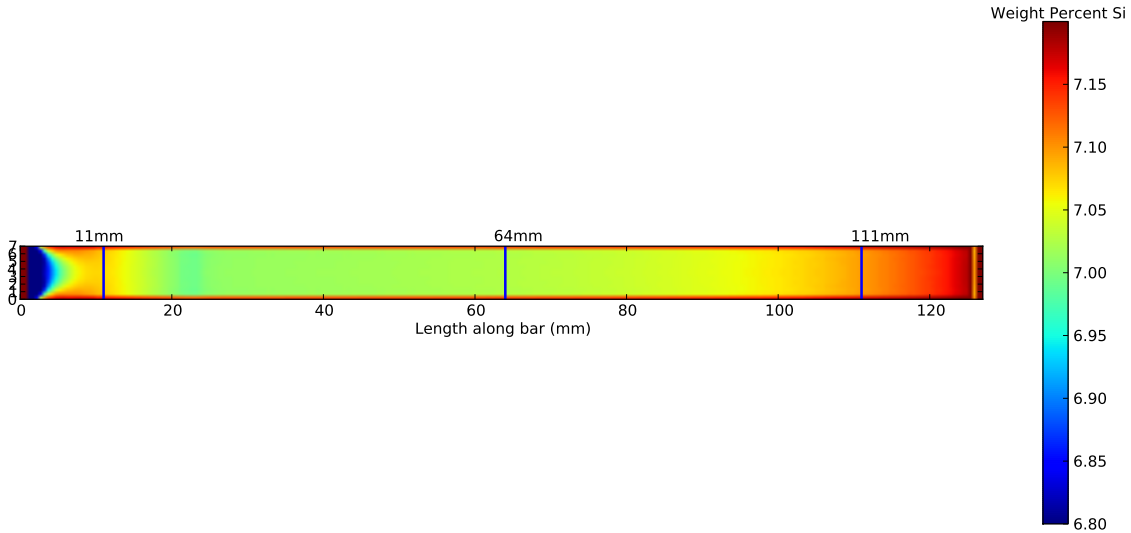


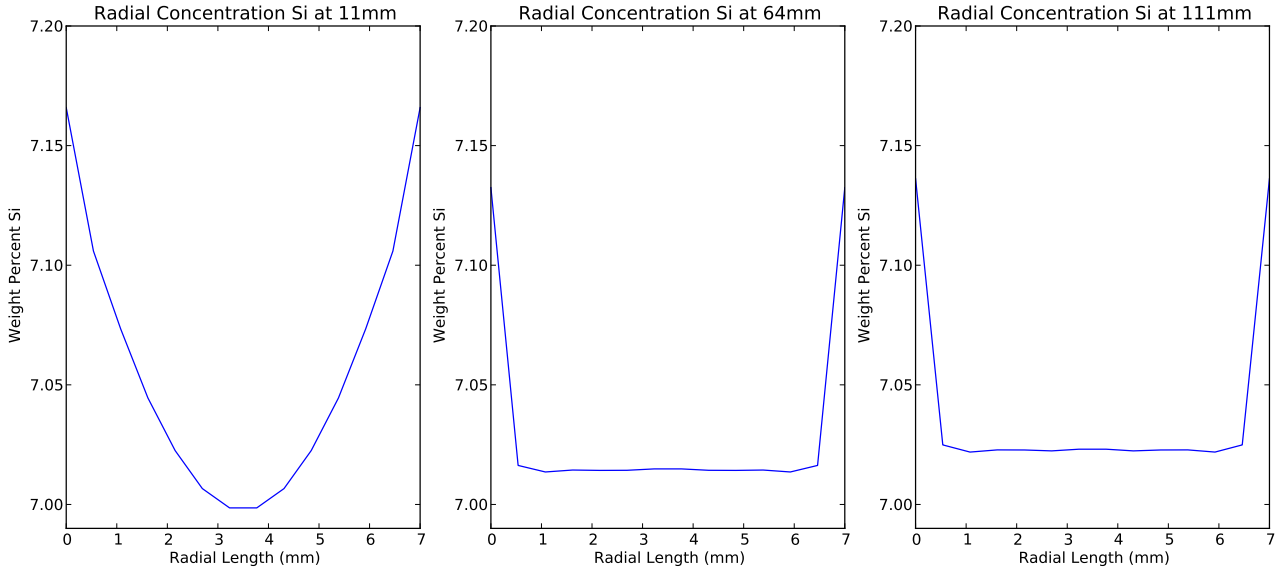
Modeling The Effect of Gravity on Macrosegregation during Directional Solidification

Alexander Miles
Advisor:
Dr. Robert Erdmann

Background
Terrestrial
Space Based
Methods
Results
Summary
Future Work
Acknowledgements

Results - Without Gravity, Slow Cooling



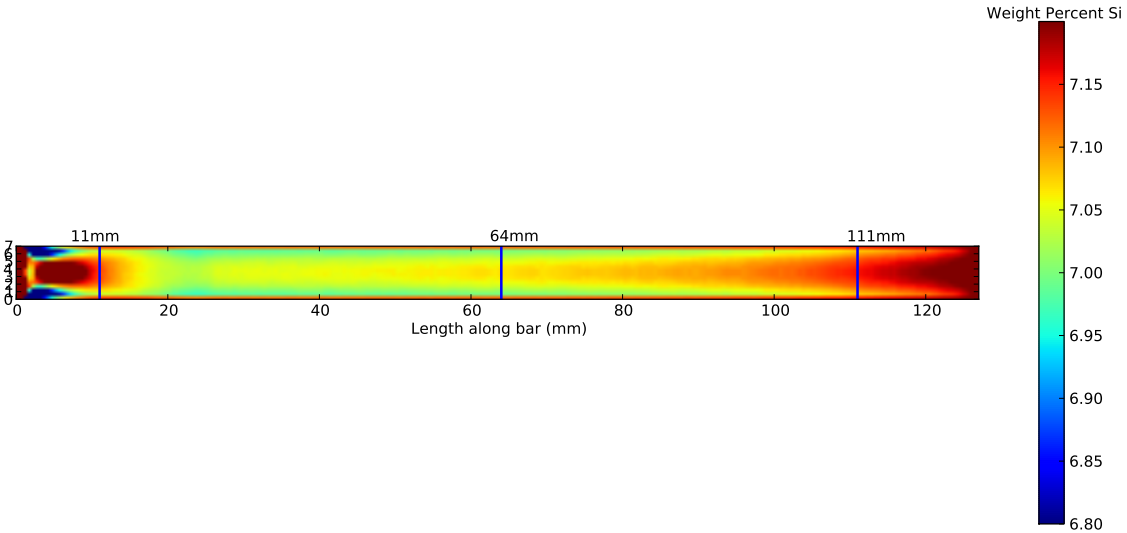


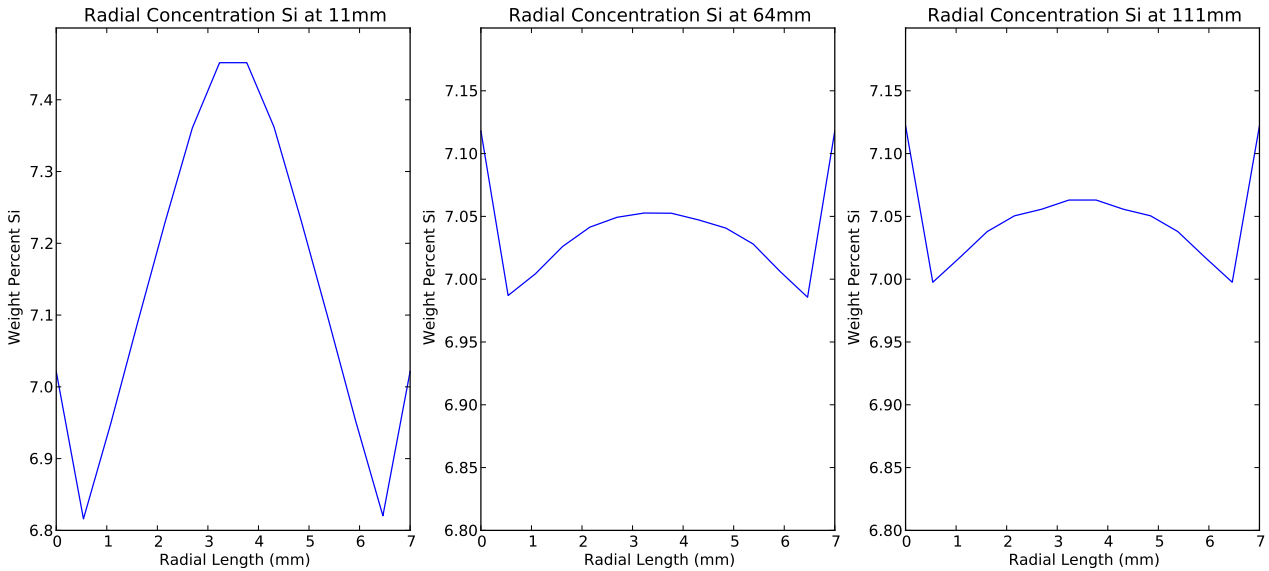
Modeling The Effect of Gravity on Macrosegregation during Directional Solidification

Alexander Miles
Advisor:
Dr. Robert Erdmann

Background
Terrestrial
Space Based
Methods
Results
Summary
Future Work
Acknowledgements

Results - With Gravity, Rapid Cooling



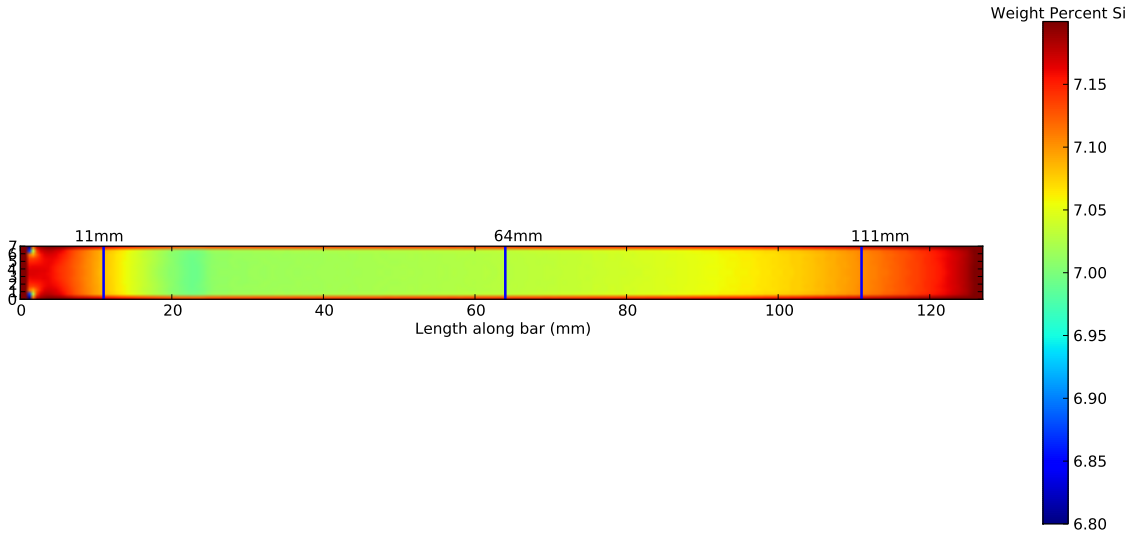


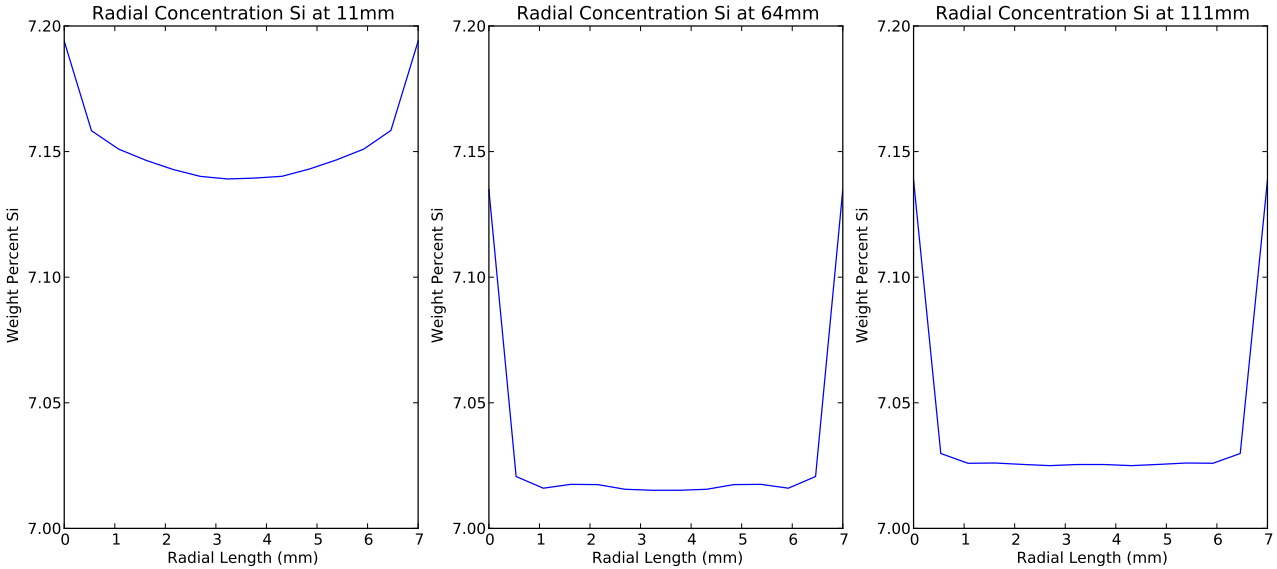
Modeling The Effect of Gravity on Macrosegregation during Directional Solidification

Alexander Miles
Advisor:
Dr. Robert Erdmann

Background
Terrestrial
Space Based
Methods
Results
Summary
Future Work
Acknowledgements

Results - Without Gravity, Rapid Cooling





Modeling The Effect of Gravity on Macrosegregation during Directional Solidification

Alexander Miles
Advisor: Dr. Robert Erdmann

Background
- Terrestrial
- Space Based

Methods

Results

Summary

Future Work

Acknowledgements

Summary

- More consistent average composition without gravity
- Without gravity, the liquid does not convect
- Without convection, less segregation results
- Rapid cooling yields more segregation

Future Work

- Improve boundary conditions to better reflect reality
- Improve granularity of simulated domains, and calculation speed
- Improve numeric stability near boundaries

Acknowledgements and Thanks

The modeling was just a small part of a larger joint project undertaken by NASA, DLR, ESA, University of Arizona, and Cleveland State University. I want to thank the NASA Space Grant program, Dr. David Poirier, and Dr. Robert Erdmann for making my participation in this project possible.