50th AIAA Aerospace Sciences Meeting, 9 - 12 Jan 2012
26th Symposium on Gravity - Related Phenomena in Space Exploration

Disruption of an Aligned Dendritic Network by Bubbles during Re-melting in a Microgravity Environment

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Solidification Processing of Metals and Alloys in a Microgravity Environment

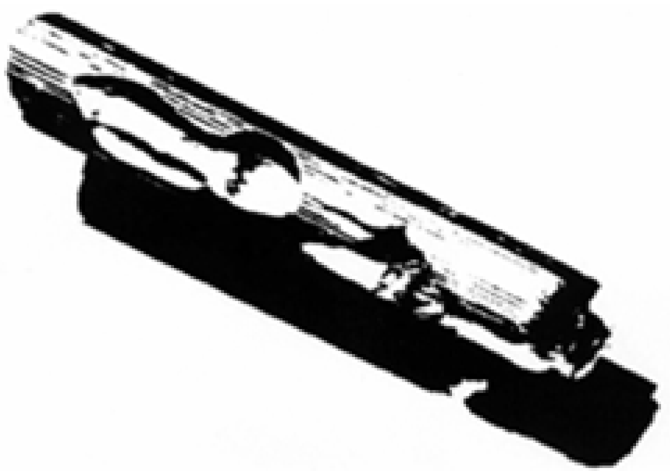
Advantages: Minimize Thermo-Solutal Convection
Minimize Buoyancy Effects

Intent: Produce Segregation Free Samples Grown Strictly by Heat Transfer and Solute Diffusion

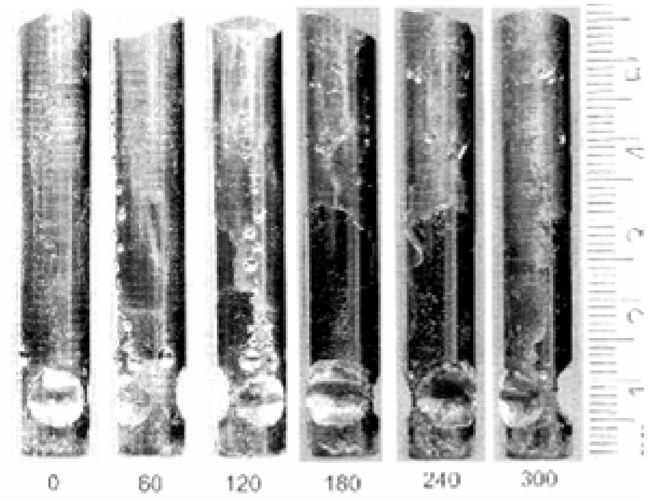
Purpose: Better Understand the Relationship between Processing – Microstructural Development

Application: Maximize Material Properties

Some Microgravity Processing Results



Computed Tomography Image of an Aluminum – 17.3 wt% Indium Alloy Directionally Solidified in the AGHF During the 1996 LMS Mission



Lead-Tin-Telluride Crystal processed on USMP-3 Mission

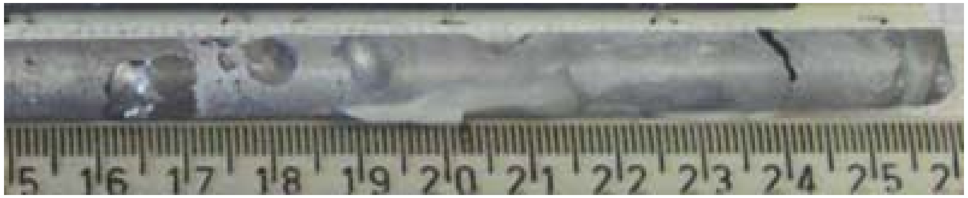
Pores or Bubbles Form in Microgravity
Recall: Buoyancy Minimized in μg

- Bubbles won’t float away
- Compromise effective heat transfer
- Initiate *gravity-independent* thermocapillary convection

Sources of Porosity

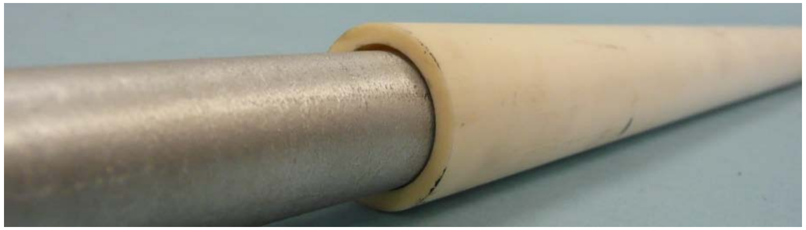
- **Evolution of dissolved gases during solidification is well documented (C.H. Tonamy, 1915)**

- **Gas generation from reactions of the melt with the crucible wall**



Al – 7wt% Si in Alumina Crucible

- **Coalescence of "empty" space between the crucible wall and inserted sample**



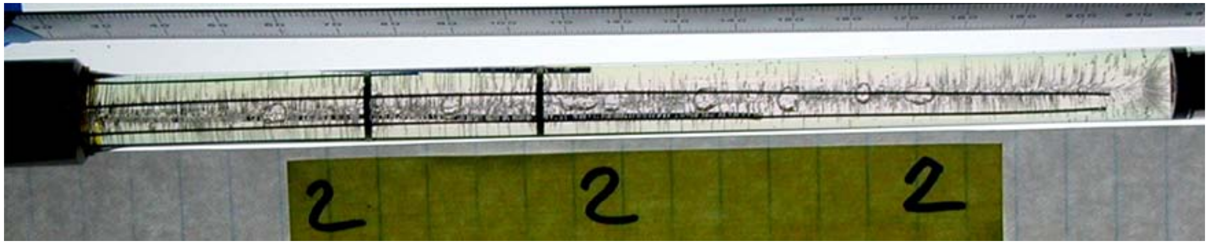
Crucible ID = 19.00 mm
Sample OD = 18.90 mm

For 200 mm long sample
~ 600 mm^3 void volume

Effect of Bubbles during Solidification Processing in a Microgravity Environment

→ Begin Pore Formation and Mobility Investigation (PFMI)

Sample Ampoule

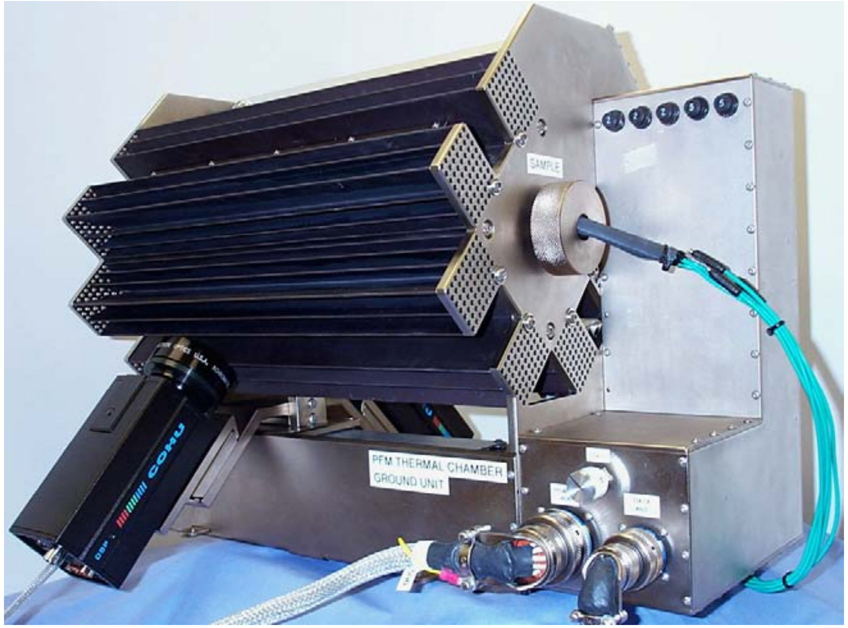


Flight sample PFMI-2
Pure SCN with Added N_2 Bubbles
~18 cm of Sample Length, 1 cm ID

- Utilizes Succinonitrile (SCN)
  - Transparent
  - Solidifies in a manner analogous to metals
  - Low melting temperature
  - Well understood material properties
  - Previously used in microgravity experiments

Experimental Hardware

Internal View of PFMI Chamber Showing Sample



PFMI Thermal Chamber

Enables Controlled, Steady-State Directional Solidification (Melting) Processing

On-Board the International Space Station

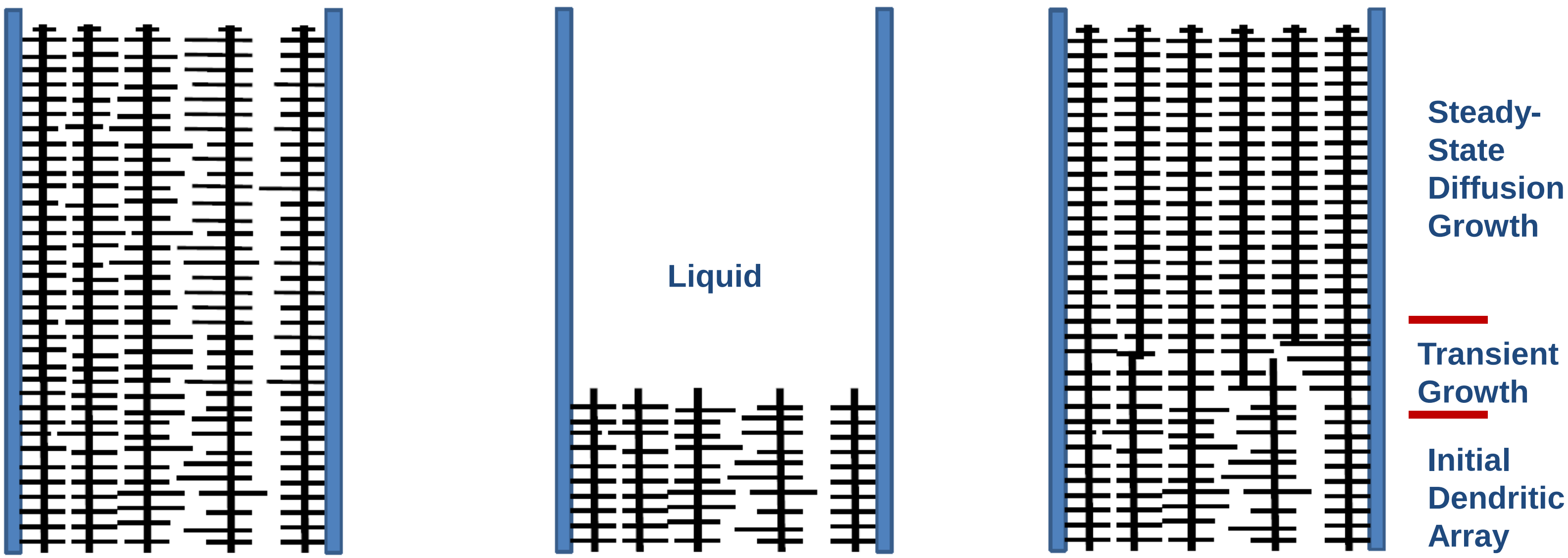
PFMI Hardware in the Microgravity Science Glovebox

Direct Observation of Succinonitrile Dendrites Growing through an Imposed Temperature Gradient. Interdendritic Porosity Develops Behind the Interface as N_2 Comes Out of Solution

Directional Solidification in a Microgravity Environment – Initial Re-melting of the Sample

(Is this a Concern??)

Ideal Schematic Microgravity Processing Scenario



1*g* Directionally Solidified Dendritic "Seed" Crystal

- ↑ Single Orientation Dendritic Array
- ↓ Non-Uniform Arm Spacing
- ↓ Segregation

Melt Back of Dendritic Array In Microgravity (Prior to initiating controlled directional solidification)

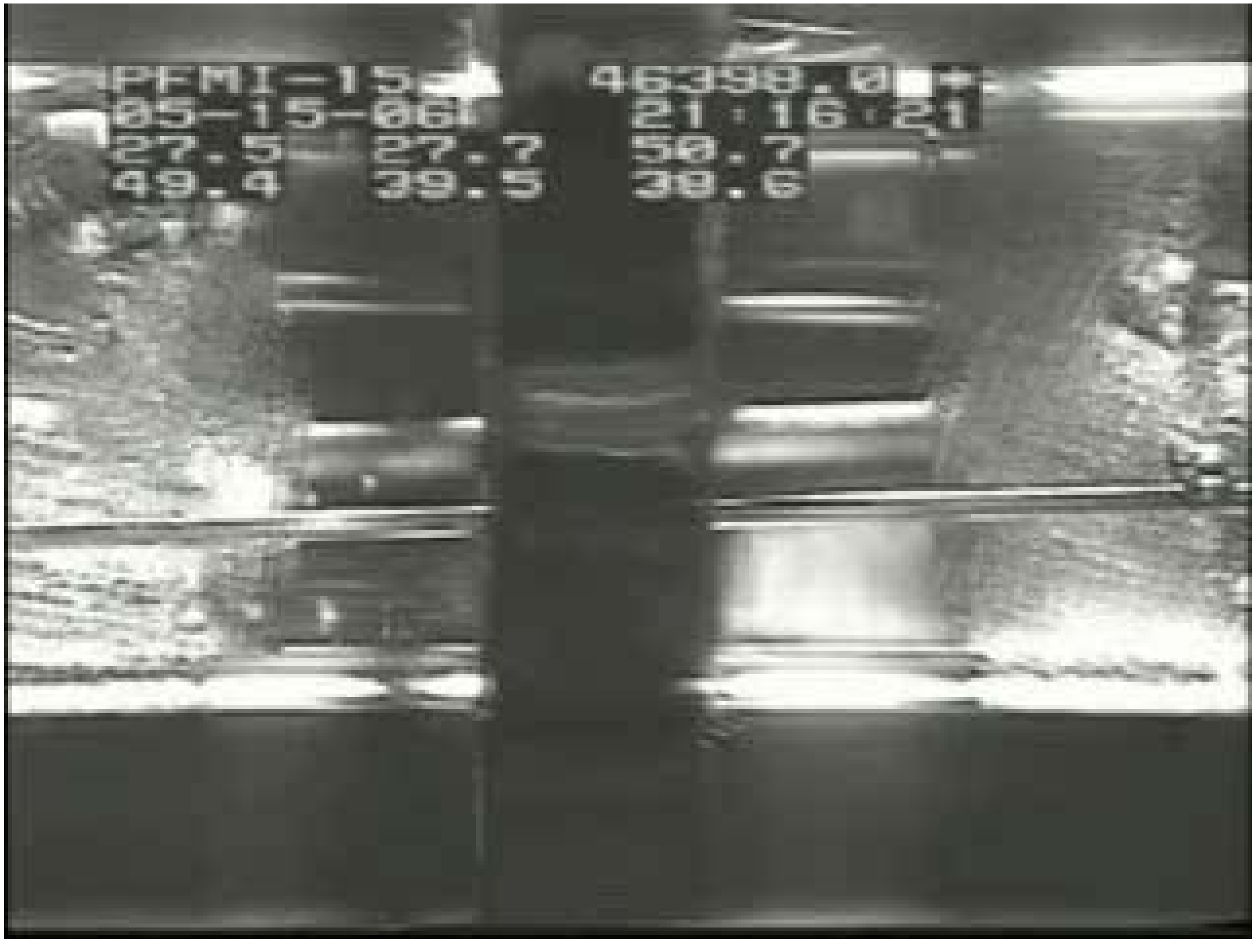
Directional Solidification in Microgravity

- ↑ Single Orientation Dendritic Array
- ↑ Uniform Dendrite Arm Spacing
- ↑ No Segregation

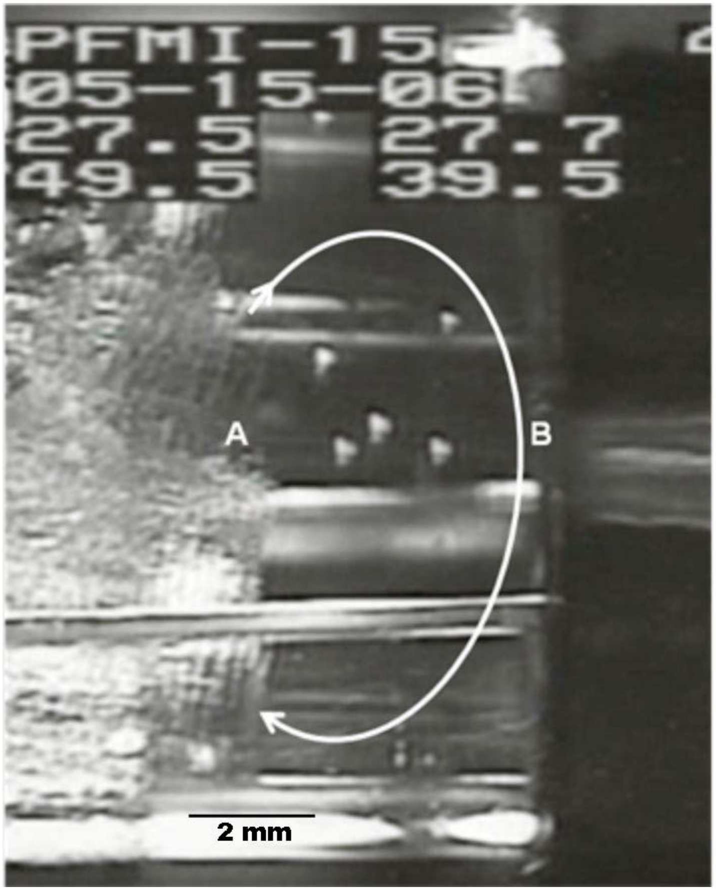
Re-melting in a Microgravity Environment

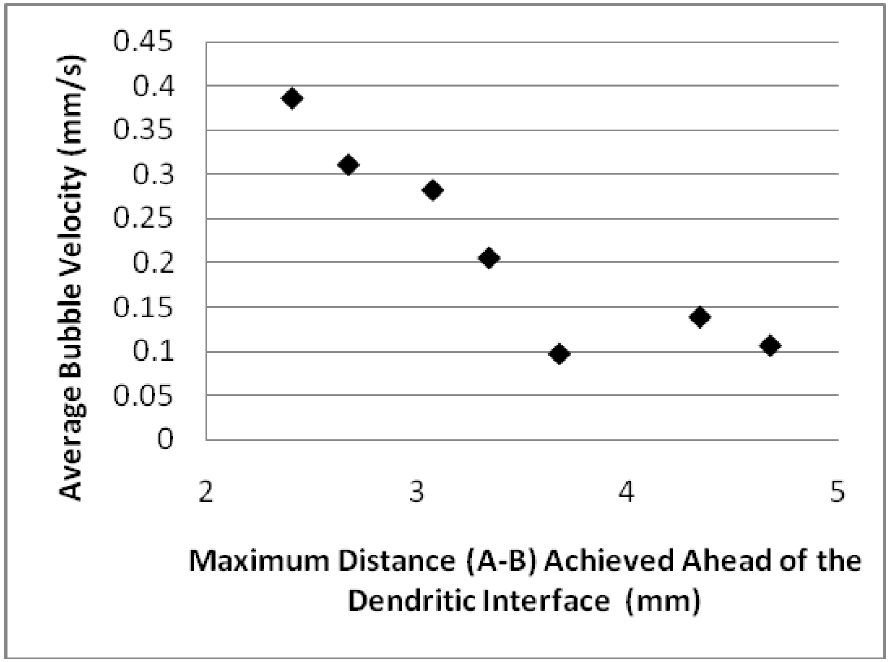
(In the Presence of Bubbles)

Convection Effects from "Large" Bubbles

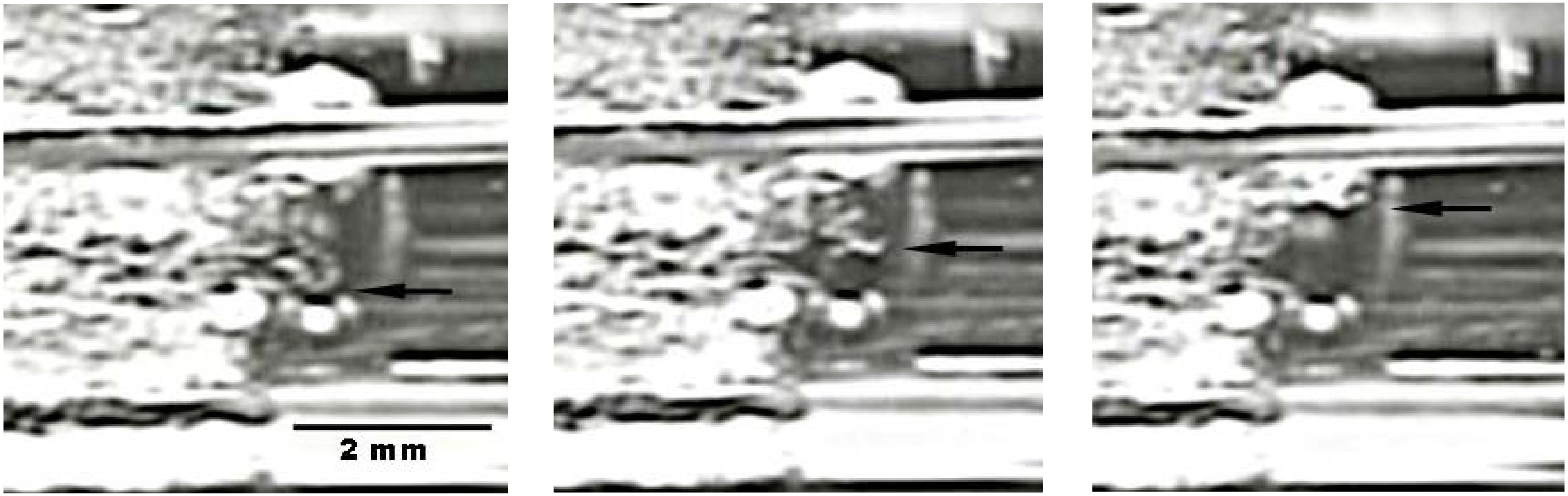


Observation and Extent of Convection via Tracer Bubbles
(time x5)





Thermocapillary flow field set up by a large bubble at the interface; velocities as established by the miniature tracer bubbles.



T = 0 seconds T = 23 seconds T = 56 seconds

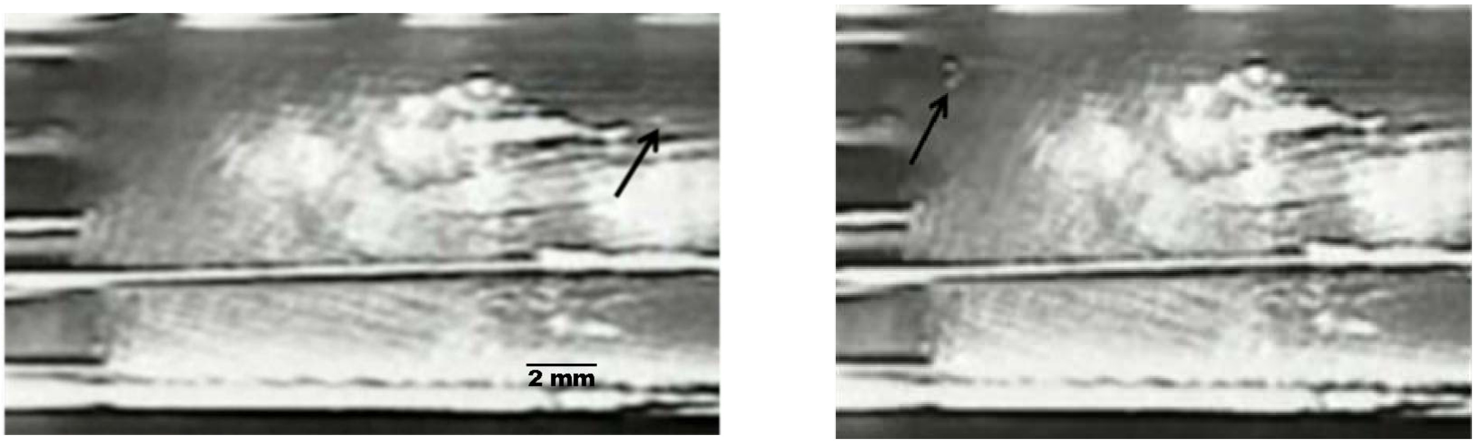
A time sequence showing dendrite fragment transportation at the solid-liquid interface

Consequence of “Large” Bubbles

- **Induce Thermocapillary Flow**
  - ♦ Raze aligned dendritic arrays
  - ♦ Transport dendrite fragments
  - ♦ Bring warm, “bulk” liquid to the interface

→ Disrupt the desired interface alignment

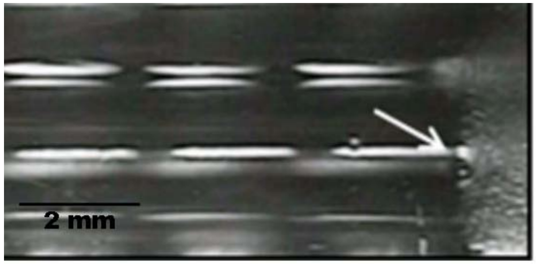
“Small” Bubble Implications



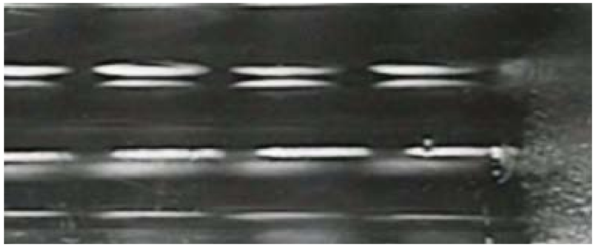
Movement of a small bubble through the mushy zone.
Note the faint trail that developed as it passed through the mushy zone

The distance in the plane of the photograph is ~9 mm, time of "flight" ~0.2 seconds

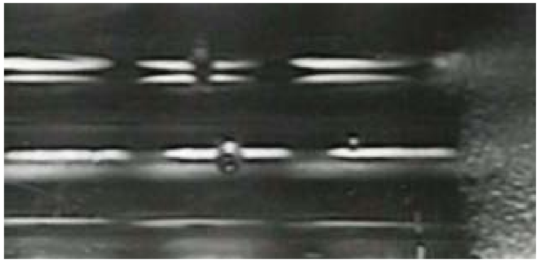
- Average (minimum) bubble velocity is 45 mm/s.
- Bubble appeared to disrupt dendrite fragments just below it



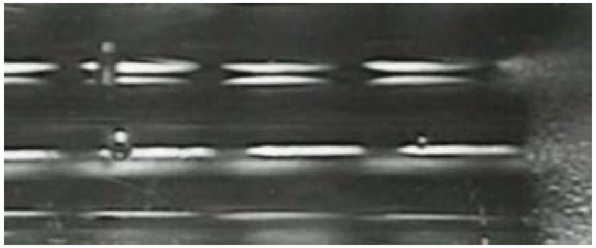
(a)



(b)



(c)



(d)

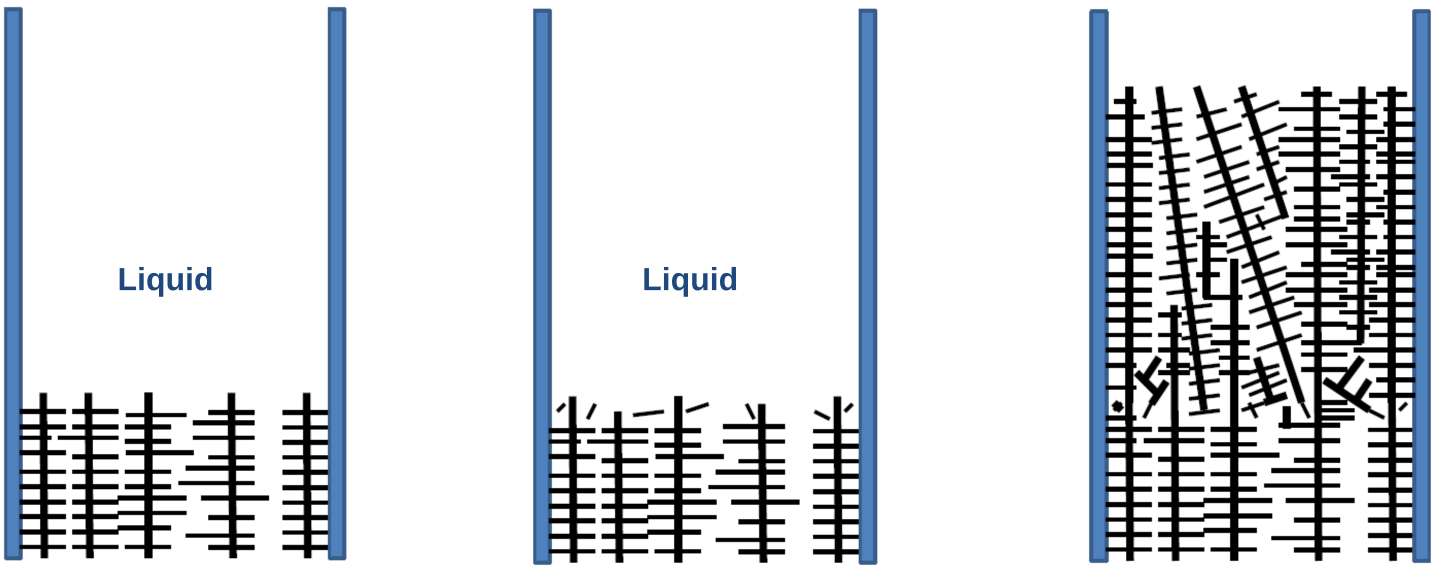
Series of photographs showing a small bubble moving up the imposed temperature gradient at a velocity of ~0.7 mms^{-1}.
(Succinonitrile – 0.24 wt% water, G = 0.12 Kmm^{-1})
~15 minutes after (d) bubble has dissolved

Consequence of "Small" Bubbles

- **Dynamic Effect**
  - ♦ **Affects a few dendrites – reposition secondary arms**
  - ♦ **Potential thermocapillary flow effects while at interface**

→ Disrupt the desired interface alignment

Consequence of Disrupting the Desired Dendritic Alignment



Melt Back of Dendritic Array In Microgravity (Prior to initiating controlled directional solidification)

Initial Solid-Liquid Interface after Disruption by Bubbles
→ Mis-oriented Dendrite Arms/Fragments

Subsequent Directional Solidification In Microgravity
→ Compromised Science
→ Compromised Material Properties

Conclusions

The quiescent Microgravity environment can be quite dynamic

Thermocapillary flow about "large" static bubbles on the order of 1mm in diameter was easily observed by following smaller tracer bubbles. The bubble induced flow was seen to disrupt a large dendritic array, effectively distributing free branches about the solid-liquid interface.

"Small" dynamic bubbles were observed to travel at fast velocities through the mushy zone with the implication of bringing/detaching/redistributing dendrite arm fragments at the solid-liquid interface.

Large and small bubbles effectively re-orient/re-distribute dendrite branches/arms/fragments at the solid liquid interface. Subsequent initiation of controlled directional solidification results in growth of dendrites having random orientations which significantly compromises the desired science.

Acknowledgment

The authors are grateful to Peggy Whitson, Mike Foale, and Ed Lu for conducting the experiments aboard the International Space Station.

Support from the PFMI and Glovebox teams, the NASA/Marshall Space Flight Center Engineering Directorate, the Telescience Support Center (TSC), and the Huntsville Operations Support Center (HOSC) is gratefully acknowledged.

Back Up Slides

(a)

(b)

(c)

(d)

Series of photographs (a-d) over a 37 second period that show interface melt back, emergence of a bubble on the upper right side (arrow point in a), and displacement of the dendritic network at the solid-liquid interface. The molten zone is initiated by the ring in the center of the photograph; it is positioned over an in-situ thermocouple tip which is currently reading 50.9° C.