N93-22645

MATERIALS SCIENCE RESEARCH IN MICROGRAVITY

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ABSTRACT

There are several important attributes of an extended duration microgravity environment that offer a new dimension in the control of the microstructure, processing and properties of materials. First, when gravitational effects are minimized, buoyancy driven convection flows are also minimized. The flows due to density differences, brought about either by composition or temperature gradients will then be reduced or eliminated to permit a more precise control of the temperature and the composition of a melt which is critical in achieving high quality crystal growth of electronic materials or alloy structures. Secondly, body force effects such as sedimentation, hydrostatic pressure and deformation are similarly reduced. These effects may interfere with attempts to produce uniformly dispersed or aligned second phases during melt solidification. Thirdly, operating in a microgravity environment will facilitate the containerless processing of melts to eliminate the limitations of containment for reactive melts. The noncontacting forces such as those developed from electromagnet, electrostatic or acoustic fields can be used to position samples. With this mode of operation, contamination can be minimized to enable the study of reactive melts and to eliminate extraneous crystal nucleation so that novel crystalline structures and new glass compositions may be produced. In order to take advantage of the microgravity environment for materials research it has become clear that reliable processing models based on a sound gound based experimental experience and an established thermophysical property data base are essential.

Materials Science Research in Microgravity

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MATERIALS SCIENCE DISCIPLINE

Goals

- Develop the basic understanding of relationships between microstructure and properties of materials during microgravity processing.
- Apply process modeling and advanced processing concepts to achieve designed microstructures.

Objectives

- Utilize the microgravity environment to advance the understanding of materials processing, including phase transformations during solidification and deposition, transport phenomena and structure-property relationships.

Microgravity Environment	Materials Response
• Buoyancy Driven Convection Flows Minimized	Precise Temperature and Composition Control for High Quality Crystals
• Body Force Effects Minimized	Uniform Spacing and Alignment in Multiphase Materials
• Containerless Melt Processing	Eliminate Contamination and Nucleation Due to Containment
• Interfacial Phenomena	Wetting and Surface Energy Driven Flows

Benchmark Materials

Priorities

Technological Applications

> Containerless Processing
> Directional Solidification/Crystal Growth
> Casting

Science Knowledge Base

1. Solidification Kinetics and Undercooling
2. Microstructural Morphology/Prediction
3. Process Analysis and Modeling
4. Interfacial Phenomena

Critical Support Base

- Ground based experience
- Thermophysical property data

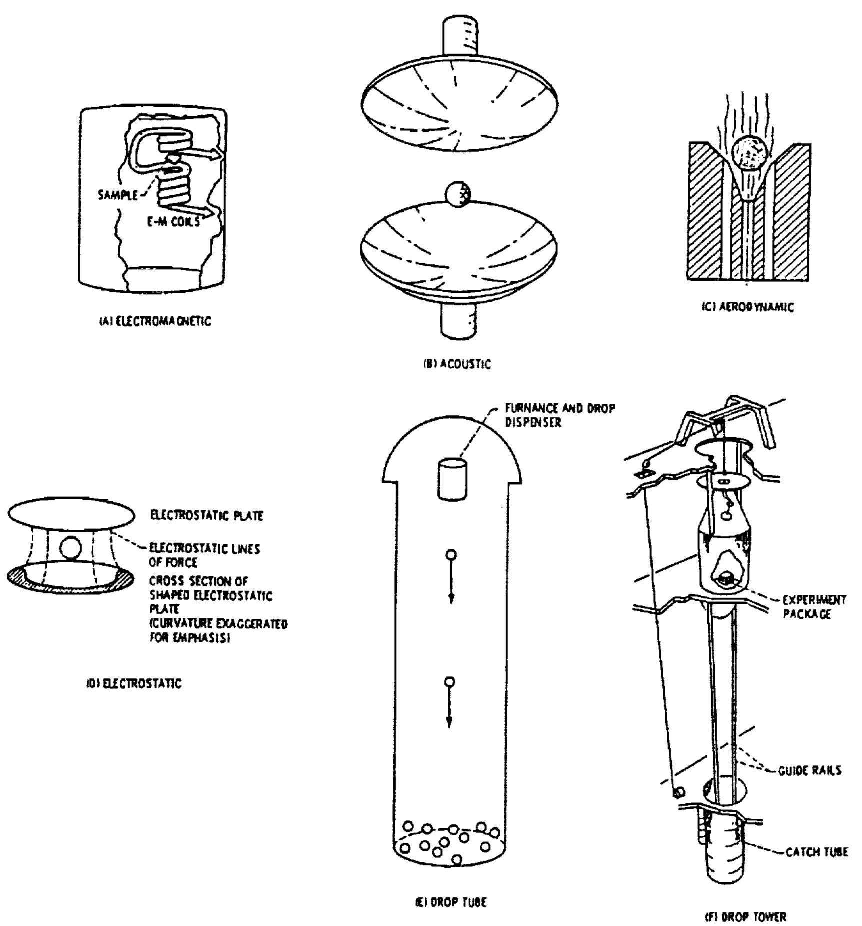
Research Areas

- Solidification Kinetics and Undercooling
  - Nucleation
  - Undercooling
  - Metastable Phase Development
  - Competitive Growth
  - Microstructural Transitions
  - Glass Formation
- Microstructural Morphology/Prediction
  - Plane Front Solidification
    - > Single Crystals
    - > Aligned Composites
    - > Phase Spacing
  - Interface Instability
    - > Cells
    - > Dendrites
    - > Segregation
  - Microstructural Scale
    - > Coarsening/Coalescence
    - > Scaling Laws
- Process Analysis and Modeling
  - > Macrosegregation
  - > Heat and Mass Transport Analysis
  - > Structure Prediction

- Interfacial Phenomena

  > Surface Energy Driven Flows
  (Temperature or Composition Gradients)
  > Particle Incorporation
  > Wetting Behavior
  > Bubble Formation - Porosity Control
  > Joining Applications

8-5. CONTAINERLESS PROCESSING TECHNIQUES



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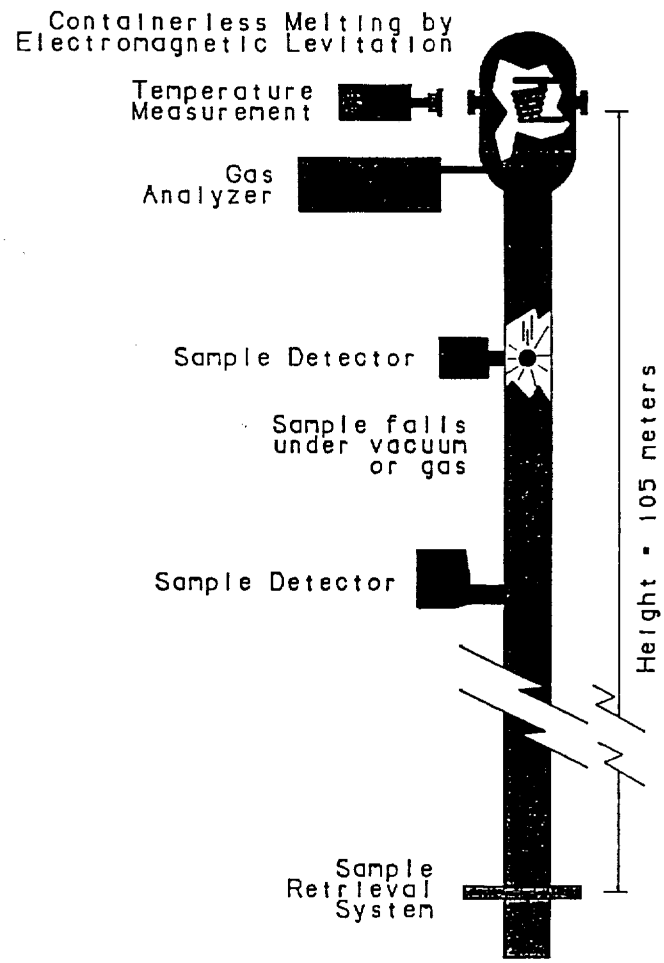
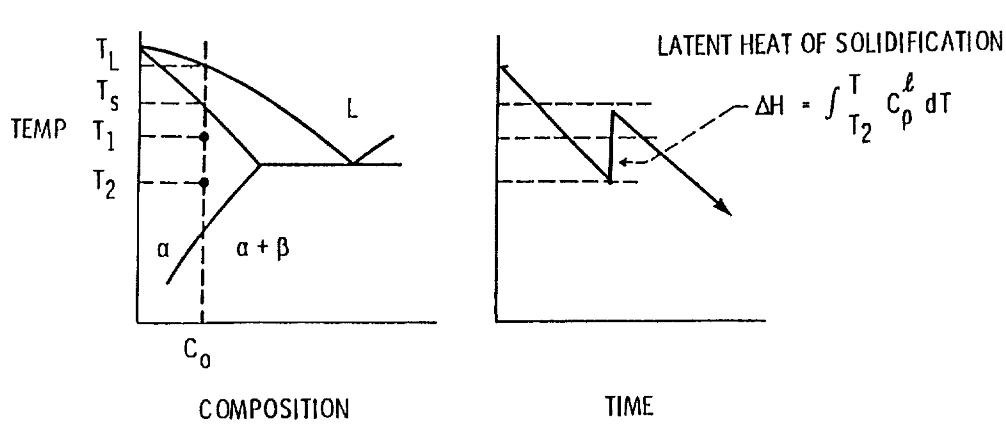


Marshall Space Flight Center
4.6 second Drop Tube Facility

B. SUPERCOOLING (UNDERCOOLING)



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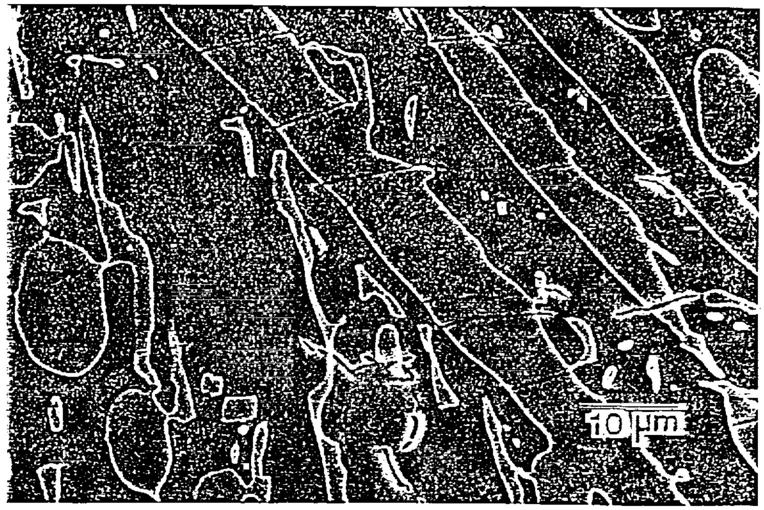
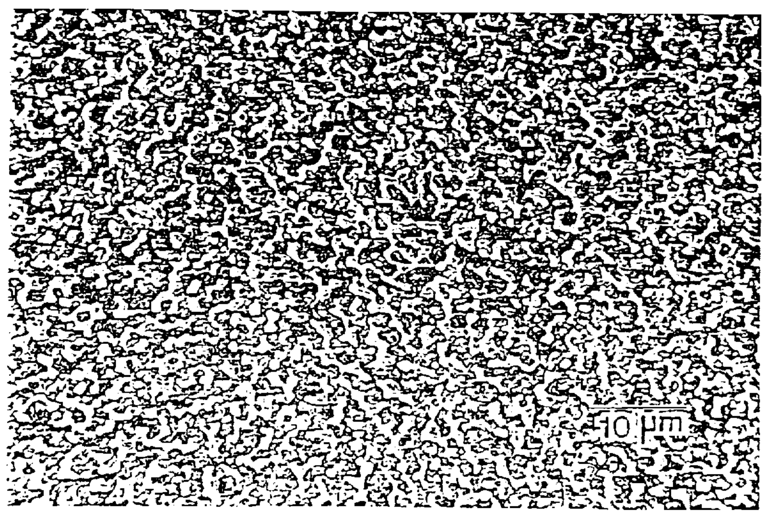
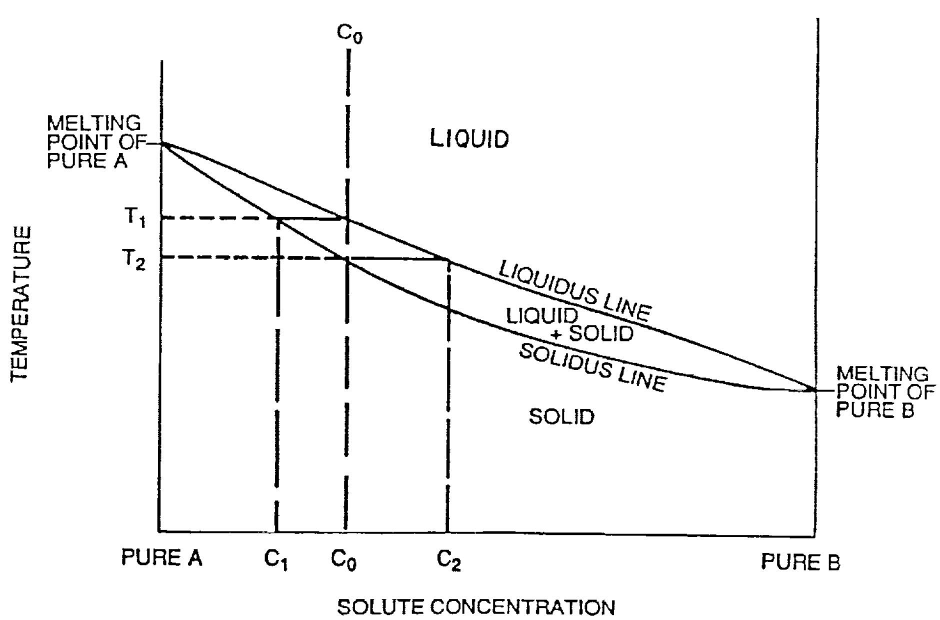
Nb-25 at.% Ge Solidification Microstructures

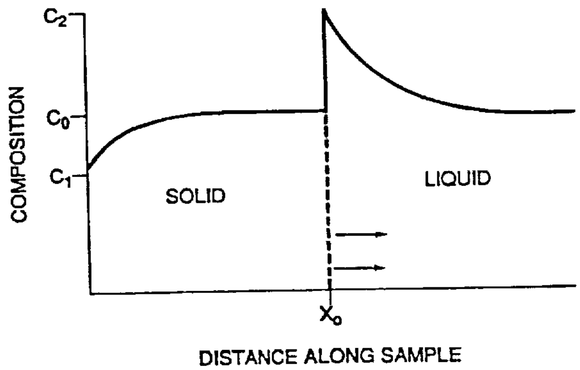
As-Cast

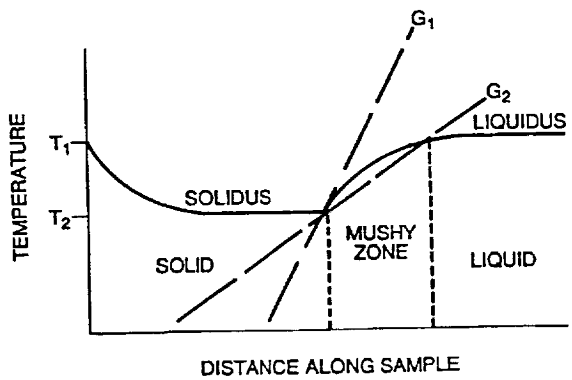


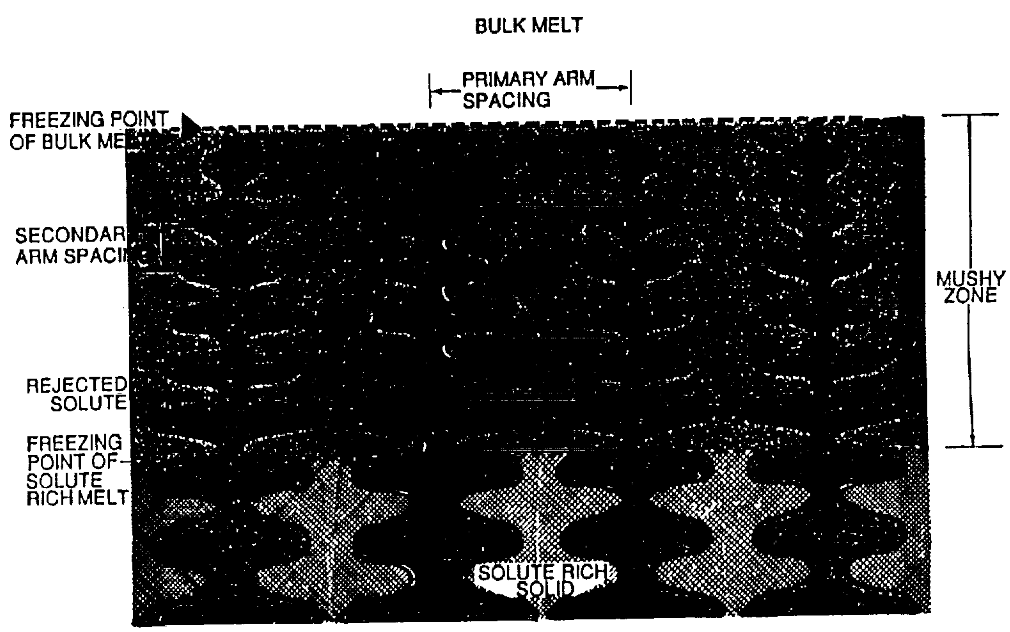
Drop Tube Processed
(ΔT = 530K)

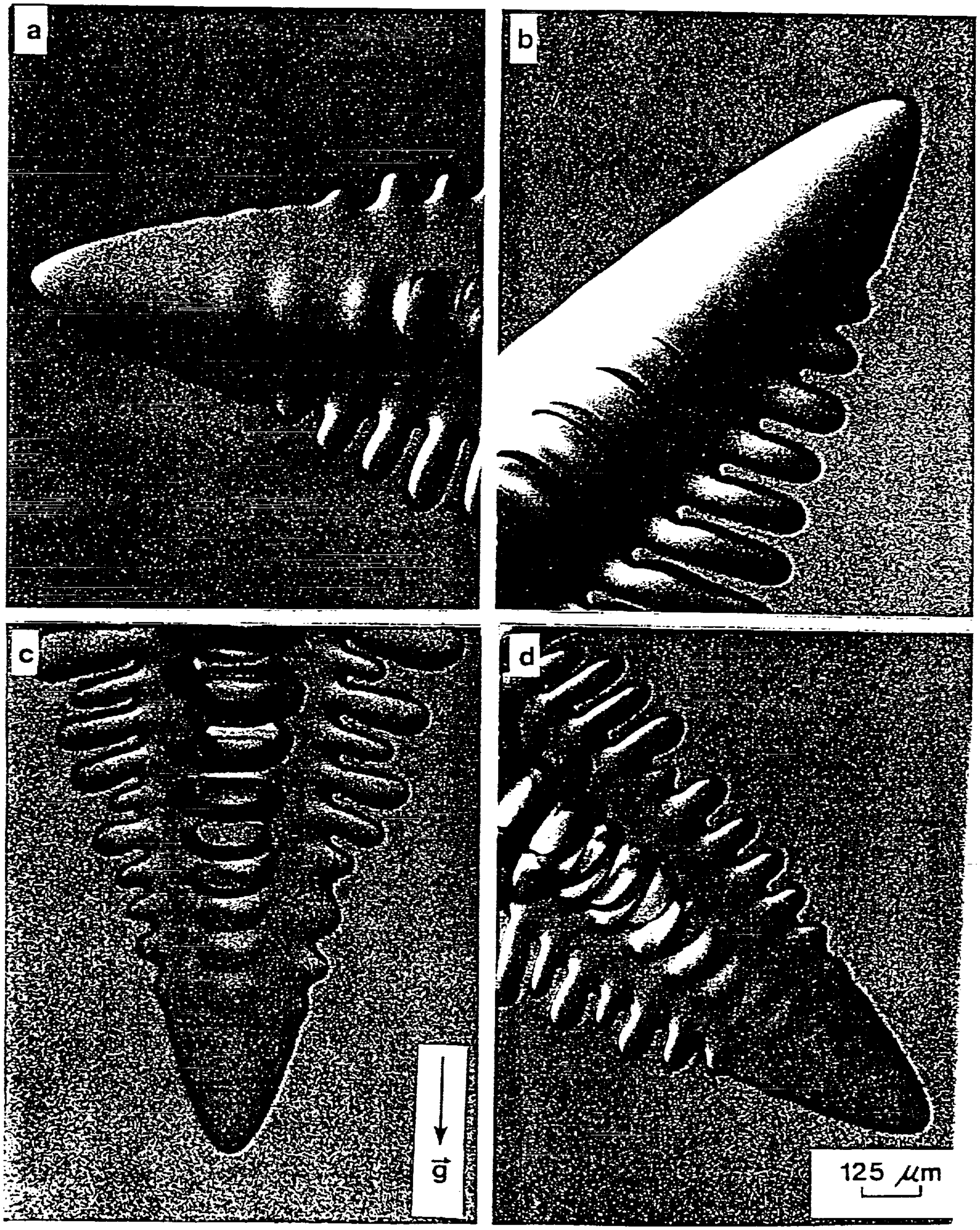




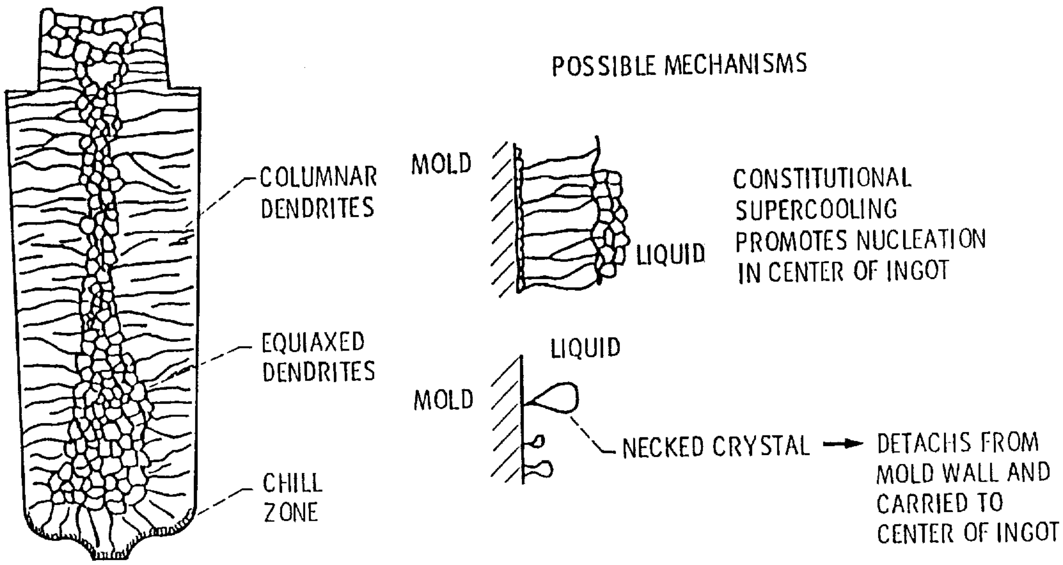

C2
C0
C1
COMPOSITION
SOLID
LIQUID
X0
DISTANCE ALONG SAMPLE


G1
G2
LIQUIDUS
T1
T2
TEMPERATURE
SOLIDUS
SOLID
MUSHY ZONE
LIQUID
DISTANCE ALONG SAMPLE


BULK MELT
PRIMARY ARM SPACING
FREEZING POINT OF BULK ME
SECONDAR
ARM SPACI
REJECTED SOLUTE
FREEZING POINT OF SOLUTE RICH MELT
MUSHY ZONE
SOLUTE RICH SOLID


a
b
c
d
g
125 μm

G-1. COLUMNAR - EQUIAXED TRANSITION



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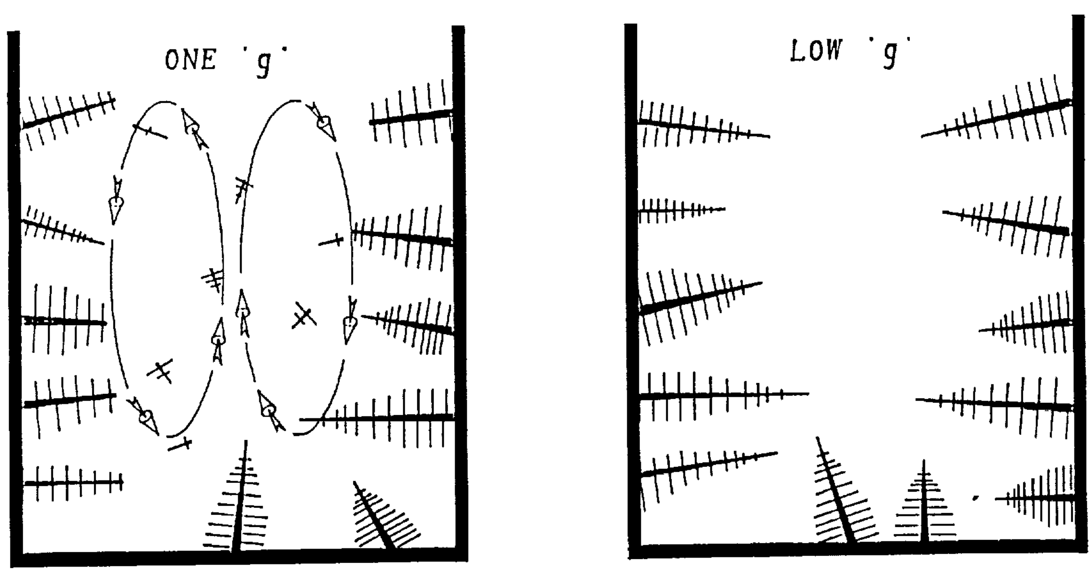
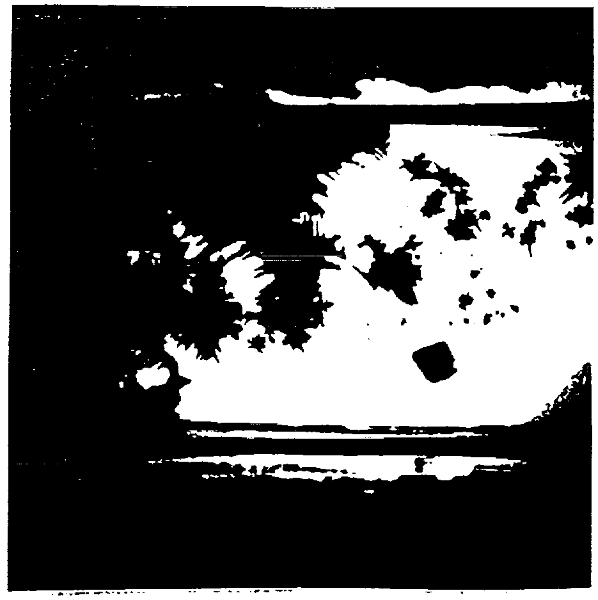
NASA
C-88-12974

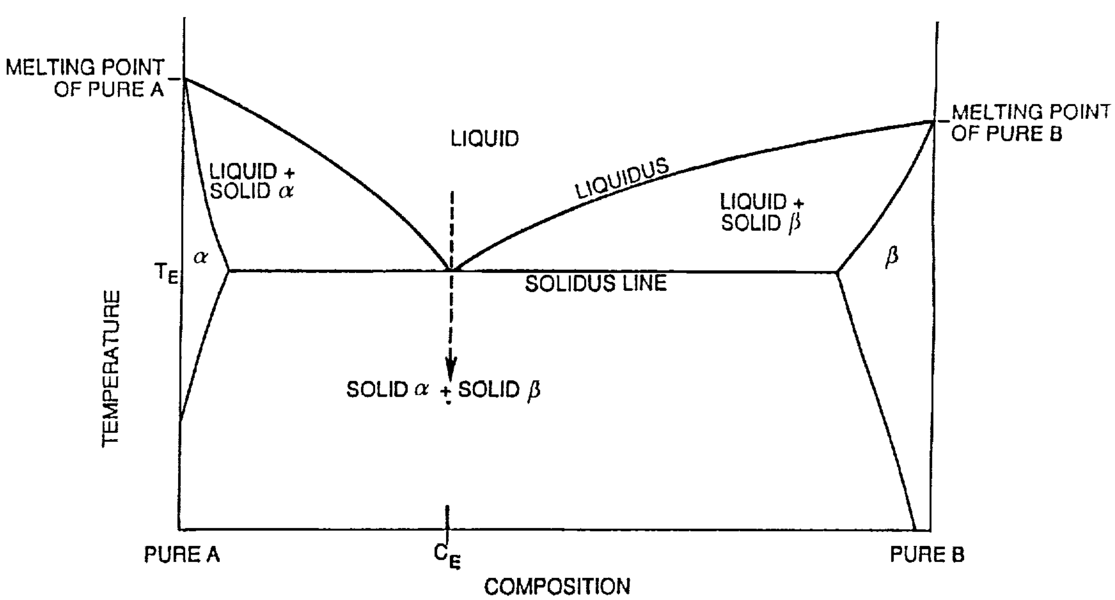
GRAIN MULTIPLICATION

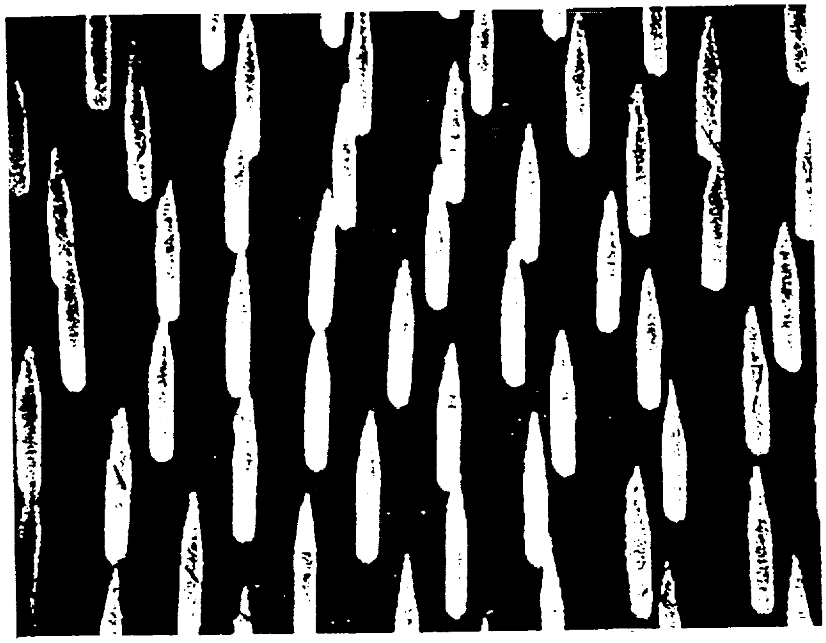


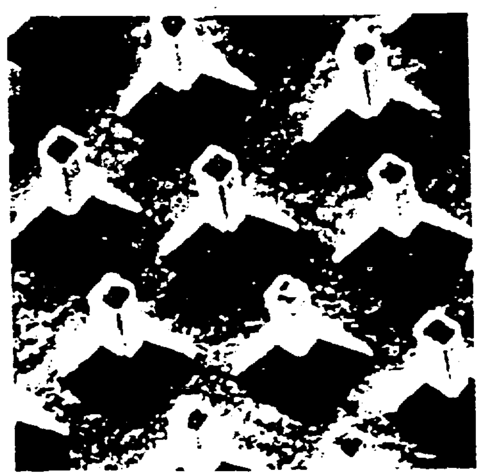
Convection causes melting or breaking off of dendrite tips.

Dendrites grow with minimal convective disturbance

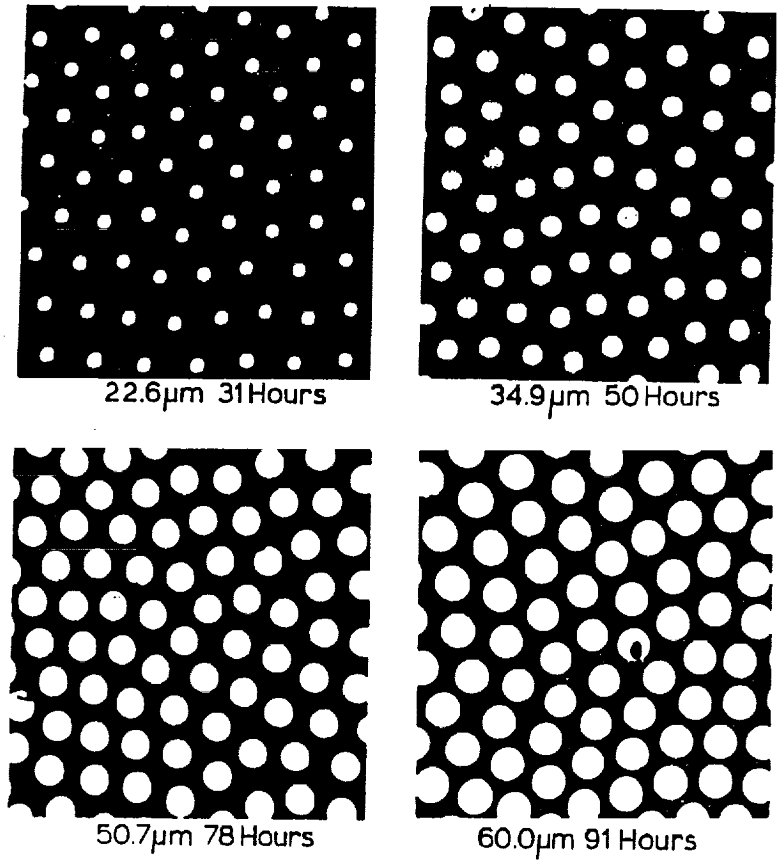



MELTING POINT OF PURE A
MELTING POINT OF PURE B
LIQUID
LIQUIDUS
LIQUID + SOLID α
LIQUID + SOLID β
α
β
T_E
SOLIDUS LINE
SOLID α + SOLID β
TEMPERATURE
PURE A
C_E
PURE B
COMPOSITION





Examples of in situ composites. An electron emitter formed from 0.3 micron tungsten single crystal fibers embedded in a zirconia matrix is shown at the top. A section of a nickel-based superalloy used for turbine blades is shown at the bottom. The matrix material has been etched away to reveal the single crystal tantalum carbide reinforcing fibers that allow the blade to operate for longer times at higher temperatures. Such structures can generally be made on earth only at the eutectic composition. Microgravity offers the possibility of extending the range of compositions to optimize the resulting structure. (Photographs courtesy of General Electric)



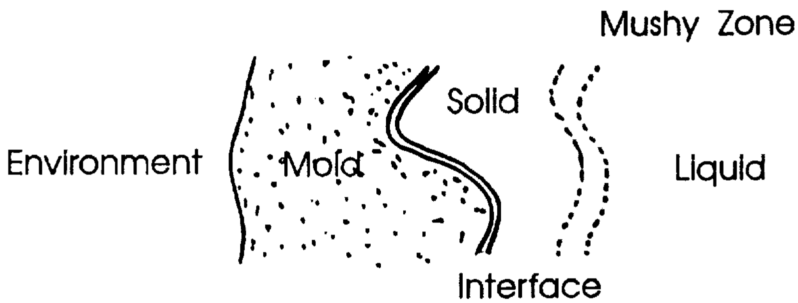
Hole Diameter vs. Time
10% HNO_3

UNIVERSITY OF WISCONSIN MADISON

Process Analysis and Modeling

- Assess role of individual variables
- Control and Vary Independently Process Parameters
- Reduce Complex Processes to Fundamental Units
- Explore Regimes Unavailable to Experiment
- Design Experiments to Emphasize Phenomena of Interest
- Interpret Results
- Improve Yield from Microgravity Experiments

Solidification Processes

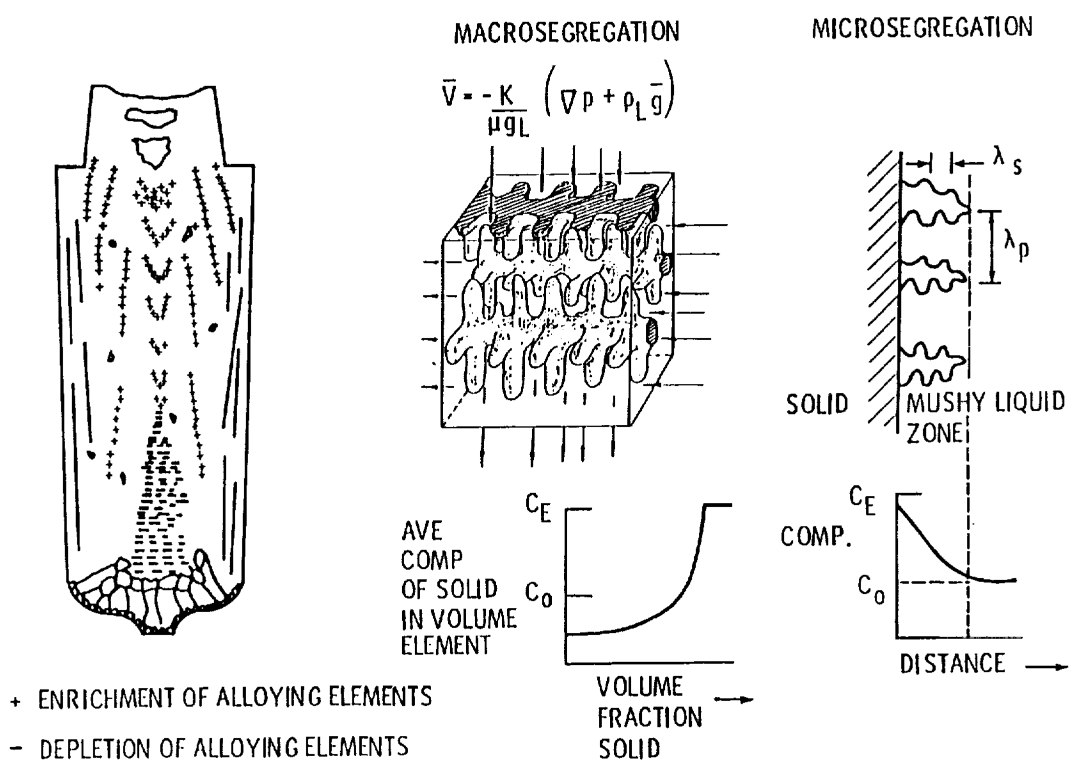


Heat Transfer Coefficients
    Interface, environment

Heat evolution
    Mushy zone model

Material properties

G - 3. SEGREGATION



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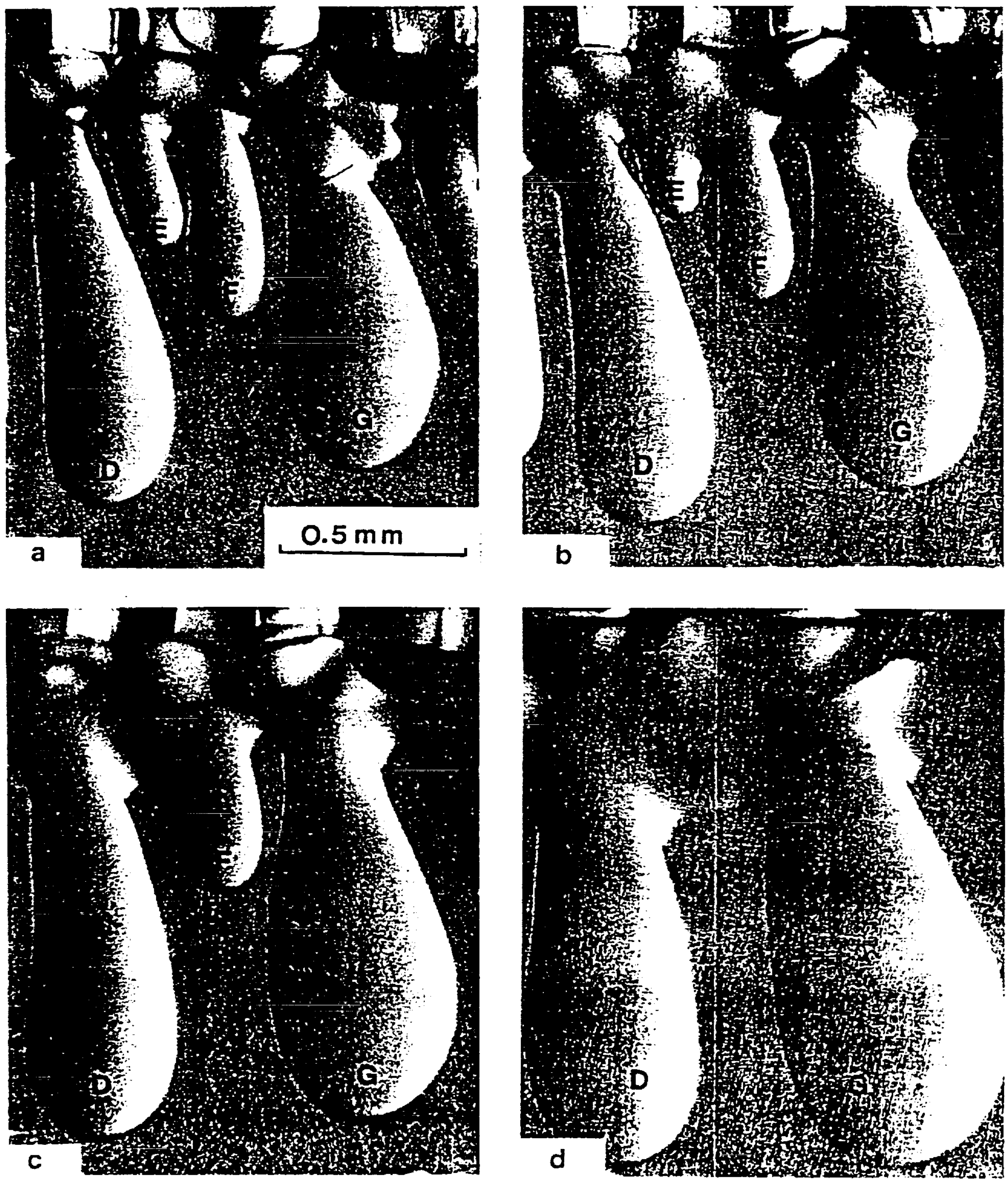
A-1. DENDRITE COARSENING



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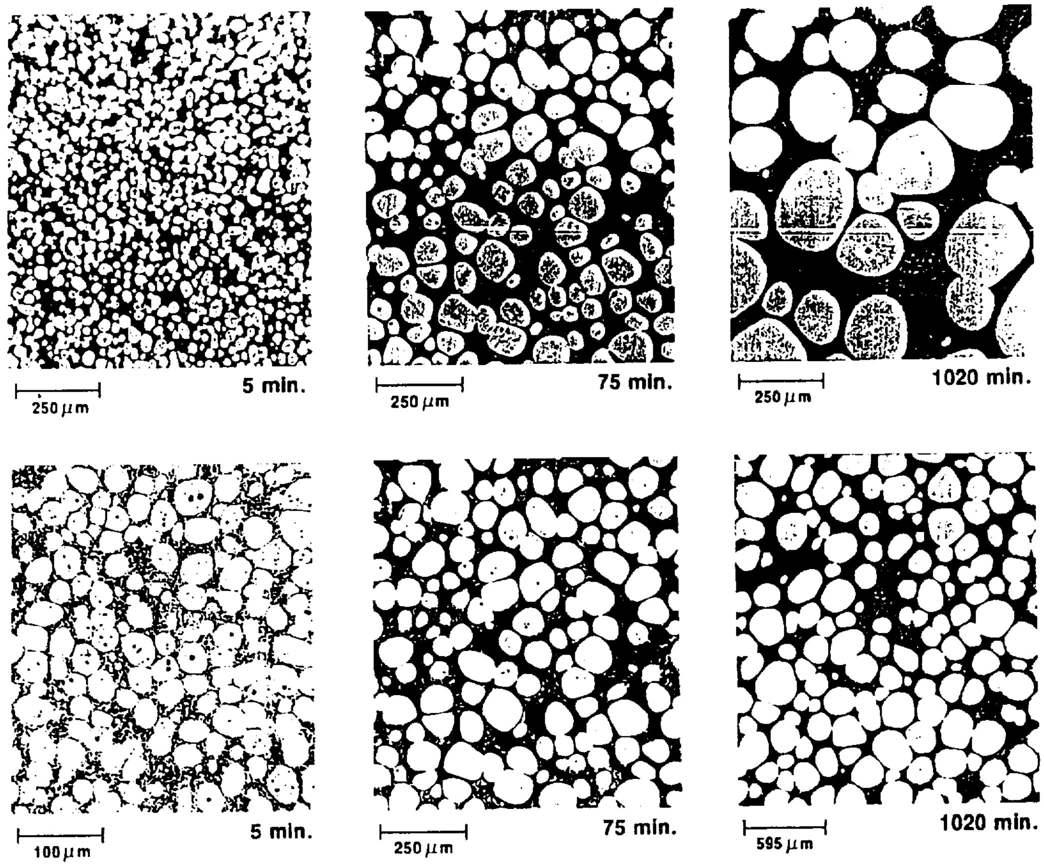
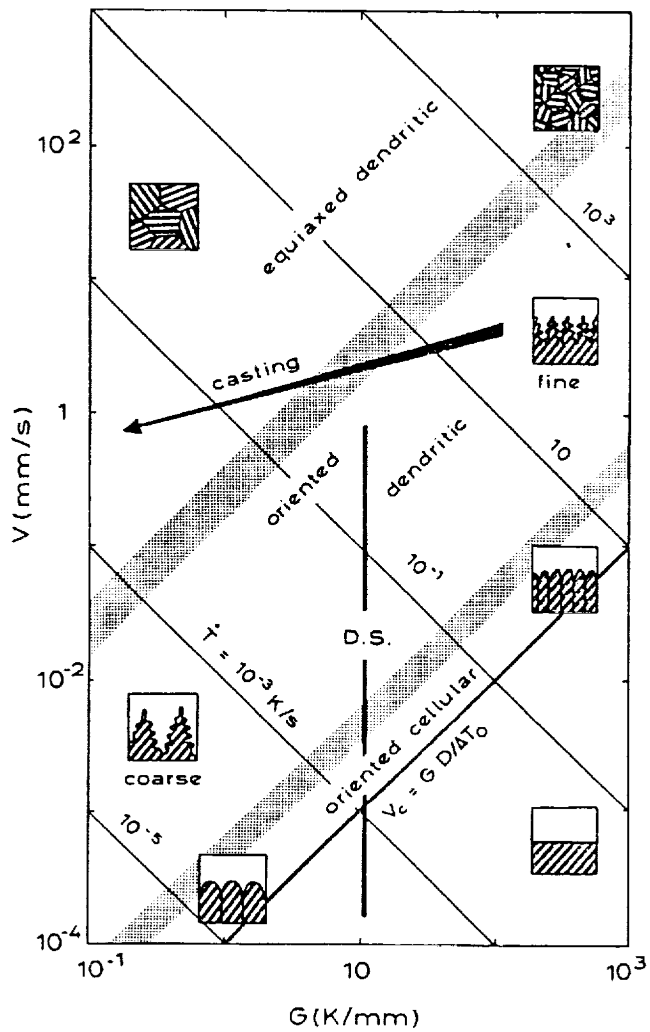
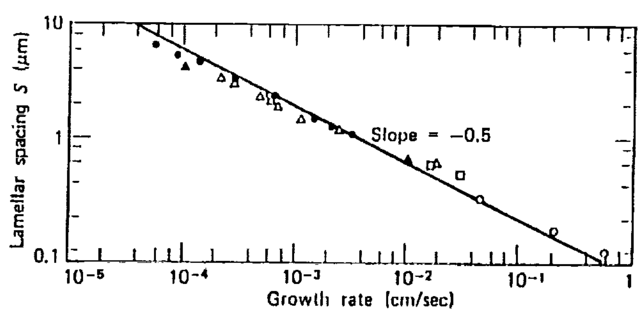
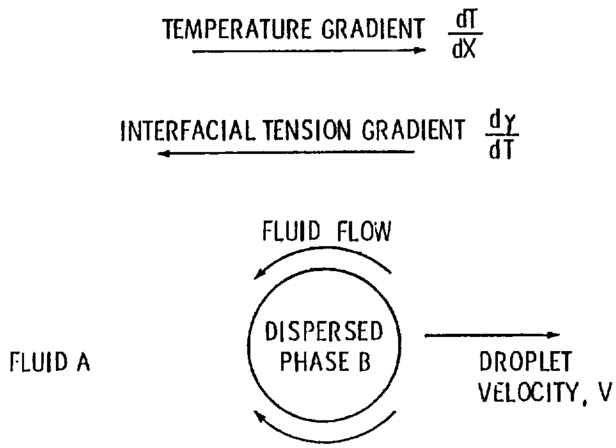

250 μm
5 min.
250 μm
75 min.
250 μm
1020 min.
100 μm
5 min.
250 μm
75 min.
595 μm
1020 min.


V (mm/s)
G (K/mm)
equiaxed dendritic
casting
fine
oriented
dendritic
D.S.
oriented cellular
coarse
$V_c = G D/\Delta T_o$
$\dot{T} = 10^{-3}$ K/s
10^{-5}
10^{-1}
10
10^3


Lamellar spacing S (μm)
Growth rate (cm/sec)
Slope = −0.5

C-4. THERMAL MIGRATION



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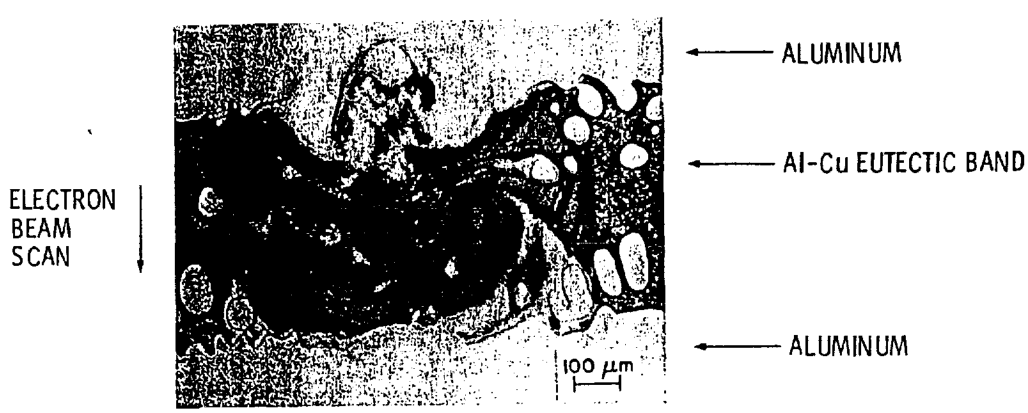
G-4. SURFACE TENSION DRIVEN FLOW



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Thermophysical Properties

- Emissivity, Electrical Conductivity, Optical Properties
- Calorimetry
  - Specific heats
  - Heats of mixing, formation, transformations, ...
- Transport Coefficients
  - thermal conductivity
  - viscosity
  - diffusion constants
- Density Data
- Thermodynamic Modulii
  - thermal expansion coefficients
  - compressibility, etc.
- Vapor Pressures and Activity Coefficients
- Surface Tension/Interfacial Energies

Research Opportunities

- Electrodeposition
- Powder Processing
- Joining
- Novel Materials
- Extraterrestrial Materials