Materials Science in Microgravity

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NASA was not the first to understand and utilize the benefits of processing materials in a microgravity environment.

William Watts of Bristol, England built a “drop tower” in 1753 to process molten lead into uniformly spherical shot for firearms.

Boughton Shot Tower
Chester, England
1799, 168’ tall

Molten lead is poured

Through a sieve

Uniform drops freefall (microgravity), buoyancy effects are minimized

Surface tension dominates forming uniform spheres

Solidified shot lands in a cushion of cooling water

Phoenix Shot Tower
Baltimore, MD, 1828
234’ - tallest structure in US
2.5 million pounds shot/year
# Long Duration Microgravity Materials Science Research

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### Foundational Era

- **Mercury / Gemini / Apollo / Soyuz Spacecraft / Skylab**
  - Soyuz 6 1969 1st Welding Experiment
  - Apollo 14 1971 Composite Casting
  - Skylab 1973-1979

### Shuttle Era

- STS3 1982 Latex Spheres
- STS9 1983 Spacelab 1
- STS17 1985 Spacelab 3
- STS51B 1985 Spacelab 2
- STS61A 1985 Spacelab D1
- STS40 1991 Spacelab LS1
- STS42 1992 IML1
- STS50 1992 USML
- STS46 1992 EUREKA
- STS47 1992 Spacelab-J
- STS55 1993 Spacelab D2
- STS57 1993 LEMZ
- STS60 1994 CLPS
- STS62 1994 USMP2
- STS65 1994 IML2
- STS73 1995 USML2
- STS76 1996 QUELD LPS
- STS77 1996 CFZF SEF
- STS78 1996 LM2
- STS94 1997 MSL
- STS87 1997 USMP4

### Materials Processing Facility

- **Skylab Materials Processing Facility**
  - **Technologies**
    - D008 Radiation in Spacecraft
    - D024 Thermal Control Coatings
    - M45 Thermal Control Coatings
    - M479 Zero-G Flammability
    - M517 Materials Processing Facility
    - M551 Metals Melting
    - M552 Exothermic Brazing
    - M553 Sphere Forming
    - M555 Gallium Arsenide Crystal Growth
    - M556 Crew Activities / Maintenance Study
    - M558 Multipurpose Furnace System
    - M556 Vapor Growth of II-VI Compounds
    - M557 Immiscible Alloy Compositions
    - M558 Radioactive Tracer Diffusion
    - M559 Microsegregation in Germanium
    - M560 Growth of Spherical Crystals
    - M561 Whisker-Reinforced Composites
    - M562 Indium Antimonide Crystals
    - M563 Mixed M V Crystals Growth
    - M564 Metal and Liquid Eutectics
    - M565 Silver Grids Melted in Space
    - M566 Copper-Aluminum Eutectics
    - T003 In-Flight Aerosol Analysis
    - T023 Coronal Magnetic Contamination Measurement
    - T027 ATM Contamination Measurement
    - T053 Earth Laser Beacon

### Skylab

- Skylab: “such tests proved that the processing of metals without using containers is feasible in space”.

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**Images:**

- **STS3 Latex Spheres**
- **STS9 InP**
- **IML1 HgI**
- **VCG**
- **USMP2 IDGE**
Establish and improve quantitative and predictive relationships between the structure, processing, and properties of materials.

- Polymers & Organics
- Metals
- Glasses & Ceramics
- Semiconductors
- Granular Materials
- Biomaterials
Microgravity Reduces Thermal and Solutal Convection

- Microgravity promotes diffusion controlled growth and the uniform solidification of microstructures

Earth-grown

Al 7% Si
Anisotropic dendrite formation

Segregation channel
Al 7% Si

Space-grown

Pb-Sn alloy
uniform microstructure
Microgravity Minimizes Sedimentation and Buoyancy

- Promotes uniform particle distributions
- Advances our understanding of coarsening and sintering

Earth

Pb-Sn alloy (Sn in white)
Particles rise to top

Space

Pb-Sn alloy
uniform particle distribution
Objective

- Semiconductors are often doped to establish specific electronic properties (i.e. n-type or p-type).
- Convection on Earth can cause the distribution of these dopants to be inhomogeneous, degrading the suitability of crystals for their intended application.
- Absence of convection in microgravity enables an uniform distribution of the dopants.

Right: Te segregation behavior revealed by etching InSb. Top portion is the seed crystal grown on Earth. Bottom section is regrowth in microgravity. Sample grown during the Skylab mission.

Microgravity Expands the Possibilities for Containerless Processing

- Enables accurate measurements of material properties such as viscosity and surface tension
- Facilitates nucleation studies
- Increases the size of crystals that can be grown containerless
- Reduces defect densities from contact with container wall

Above: Magnification of defect structures from CdZnTe samples grown on Space and on Earth. The microgravity sample was grown during the USML-1 SpaceLab mission in 1992. Growth in microgravity resulted in a 100-fold decrease in defect density as compared to Earth.

Si Float-Zone sample. The weight from gravity collapses the melt zone. The size and types of materials that can be processed are increased in microgravity.
Microgravity Enables Study of Physical Phenomena Normally Masked by Gravity

- Thermocapillary effects and surface tension effects become paramount

Soldering drop in microgravity from the ISSI investigation.

Thermocapillarity causes flux and resultant bubbles to coalesce at the junction, weakening the joint.

- Removal of pressure head effects allows the study of granular materials
- Absence of buoyancy convection enables the study of thermocapillary and solutocapillary effects in systems with free surfaces
ISS US Materials Experiments to Date

**Solidification Using a Baffle in Sealed Ampoules (SUBSA):** MSG; Dr. Aleksander Ostrogorsky
- A series of InSb semiconductors were grown doped with Te and Zn under diffusion controlled conditions.

**Pore Formation and Mobility Investigation (PFMI):** MSG; Dr. Richard Grugel:
- Vapor bubble transport due to thermocapillary forces and the resultant microstructural disruption during melting

**In Space Soldering Investigation (ISSI):** Microgravity Workbench; Dr. Richard Grugel

**Coarsening in Solid-Liquid Mixtures (CSLM):** MSG; Dr. Peter Voorhees
- Observed coarsening in Pb-Sn mixtures

**Dynamic Selection of Three-Dimensional Interface Patterns in Directional Solidification:** DECLIC DSI; Dr. Rohit Trivedi
- Observed time dependent behavior showed cyclical patterns of expanding then contracting cellular tip radii

**Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments:** MSRR LGF, SQF; Dr. David Poirier
- Examine the effects of growth speed and speed-changes (step increase in growth speed and step decrease in growth speed) on the primary dendrite distribution and morphology during steady-state directional solidification of single crystal dendritic arrays (Al 7%Si alloys).
The microgravity materials program investigators are developing experiments to be performed on ISS in the following facilities:

- Glovebox (1 investigator)
- DECLIC (1 investigator)
- Electro-Magnetic Levitator (3 investigators)
- Materials Science Research Rack (8 investigators)

Three other investigators are performing calculations or modeling in support of flight investigations.

**Current Areas of Investigation**

- Thermo-Physical Properties of Undercooled Melts
- Metals and Alloys (Solidification)
- Semiconductors – Electronic and Photonic Materials
Purpose: Engineers & scientists identify most promising engineering-driven ISS materials science experiments

Goal: Seek needed higher-performing materials by understanding materials behavior in microgravity

Open Source and Informatics: Inspire new areas of research, enhance discovery and multiply innovation

Linkage: Materials Genome Initiative

Engineering-Driven Science

Partners:
Industry
Academic institutions
DOD
NIST
Other Government agencies
International partners
NASA
CASIS
LGF and SQF Status

- LGF and SQF are furnaces on orbit that operate in the Materials Science Research Rack (MSRR)
- Sample Cartridge Assemblies (SCA)'s for both furnaces have been developed and flown by ESA
- NASA is currently developing SCA's for these furnaces
Materials Science Facilities on the ISS: Materials Science Glovebox (MSG) Facilities

**SUBSA**
Vertical gradient furnace with transparent growth zone

**PFMI**
Low temperature furnace for solidification and remelting of transparent materials

**CSLM**
Quench furnace used for coarsening experiments