Crystal Growth Furnace

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In the past century, materials science has revolutionized life on Earth. New techniques for manufacturing silicon and other electronic materials have made the computer revolution possible. This has led to smaller computers that, although they cost less and fit on a desk top, have as much power as the mainframe systems of a decade ago. Materials science research has provided medicine with powerful new tools, such as magnetic resonance imaging (MRI), co-axial tomography (CAT scans), and ultrasound scans. These tools are allowing doctors to find tumors, detect brain disorders, and even monitor a baby`s development in the womb. New materials, such as novel composites, have given us the ability to make police vests that have saved hundreds of lives. Industrial computer controls and robotics have led to increased efficiency in the manufacture of everything from pharmaceuticals to automobiles. Light-weight materials and computer controls have even improved fuel efficiency and safety in our automobiles. What then exactly is materials science, and how has it brought about these improvements to our everyday lives?

Materials science is the study of the relationships between the preparation, structure, and properties of materials. In electronic materials, for example, factors such as speed, efficiency, and reliability depend on the arrangement of atoms in the solid.

Payload Commander Bonnie Dunbar Loading Sample Cartridges into the Crystal Growth Furnace on USML-1

Atoms in many solids line up in orderly rows and columns, forming three-dimensional structures known as crystals. By melting or vaporizing a material and then studying how it changes from a liquid or a gas into a crystal, scientists can learn which conditions affect its physical, chemical, and other properties and can determine how these properties affect the material's performance. Understanding this process may enable scientists to design or enhance desired capabilities in a specific material.

The major facility to be used for such studies on the Second United States Microgravity Laboratory is the Crystal Growth Furnace. The Crystal Growth Furnace is a reusable Spacelab facility for investigating crystal growth. It was the first space-flight furnace developed by the United States to process multiple large samples at temperatures above 1,000 °C. The Crystal Growth Furnace can enable studies in high-temperature directional solidification or vapor crystal growth methods, allowing scientists to conduct a wide variety of materials science investigations.

In microgravity, the process of crystallization can be studied more carefully than on Earth because the gravity-induced phenomena that obscure or change the process are greatly reduced or eliminated. Gravity contributes to the formation of defects during the production of crystals through convection, sedimentation, and buoyancy. These gravity-induced complications result in problems ranging from physical flaws in the internal structure of the crystal (structural imperfections) to uneven distribution of the component atoms of the crystal (chemical inhomogeneity). Both problems limit how well the crystal — and the device in which it is used — performs.

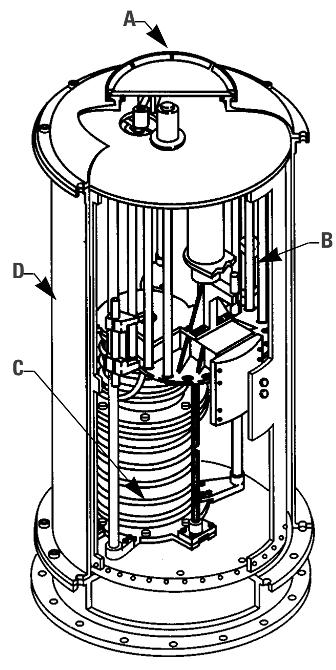
Scientists study crystals to learn about the fundamental nature of materials and to develop new applications or to improve existing ones.

Crystal Growth Furnace System Capabilities

• Reconfigurable Furnace Module	
Hot Zone Temperature	200 to 1,600 °C
Cold Zone Temperature	200 to 1,300 °C
Booster Heater Temperature	200 to 1,700 °C
Gradient Zone Length for USML-2	2.0 cm
• Control Setpoint Accuracy	±4 to 9 °C (dependent on selected temp. range)
• Control Setpoint Stability	±0.5 °C
• Furnace Translation Rate	
Directional Solidification	0.0025 to 8.30 mm/min
Rapid Translation	1200.0 mm/min
• Processing Atmosphere	argon
• Sample Size	
Diameter	up to 2.0 cm
Length	up to 20.0 cm
• Sample Exchange Mechanism Capacity	6
• Current Pulse Interface Demarcation for USML-2	
Pulse Duration	25 to 100 ms
Pulse Period	≥ 1 second
Amperage	10 to 57 amps (depending on sample resistance)

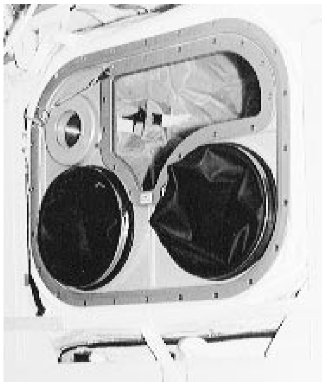
These studies require specimens in which the atoms are in a well-defined, ordered arrangement, since the properties of the crystal are directly related to that critical arrangement. One way to minimize the defects within a crystal is to use a process known as *directional solidification.* With this process, a column of liquid is allowed to cool from only one end in a mold, so that the crystal forms in only one direction. Three of the four Crystal Growth Furnace experiments on this mission will be using variations of this process. The fourth experiment will grow crystals using the vapor crystal growth technique. In vapor crystal growth, the sample is heated until it begins to sublime, a process similar to carbon monoxide gas rising from dry ice. Then, the vaporized material diffuses into a cooler section where it is deposited onto the base (*substrate*) for the crystal. A single crystal is formed as additional material is deposited on the substrate. Both the directional solidification and vapor crystal growth processes have advantages for growing certain types of crystals.

The microgravity conditions aboard the Space Shuttle provide an environment nearly free from the effects of gravitational forces that interfere with the crystal growth of materials. Basic research conducted in the Crystal Growth Furnace will increase our knowledge of the formation of many types of materials — both in space and on the ground — and, in the future, may result in improved materials, processing techniques, or products here on Earth.



A SAMPLE INSERTION PORT
B SAMPLE AMPOULE CARTRIDGE
C RECONFIGURABLE FURNACE MODULE
D EXPERIMENT APPARATUS CONTAINER

Crystal Growth Furnace



Use of this flexible glovebox on USML-1 allowed processed samples to be removed from the furnace and new samples to be loaded during the mission, proving an important concept for advanced furnace operations on space station.

Orbital Processing of High-Quality Cadmium Zinc Telluride (CdZnTe) Compound Semiconductors

Principal Investigator:
Dr. David J. Larson, Jr., Northrop-Grumman Corporation Research and Development Center, Bethpage, New York

Purpose: To determine the effects of gravity on the growth and quality of doped and alloyed compound semiconductors and to produce high-quality cadmium zinc telluride substrates with fewer physical defects and a more uniform distribution of the chemical components

Significance: Alloys are created when other elements are added to change the properties of a material composed of a single element or, as with this experiment, a pair of elements (cadmium and tellurium) that exist as a binary compound (cadmium telluride). On Earth, cadmium zinc telluride is used as a substrate for growing mercury cadmium telluride crystals, which are used to make important infrared radiation detectors. The alloying element, zinc, is added to help reduce defects in the mercury cadmium telluride crystal grown on the cadmium zinc telluride substrate by minimizing the strain where the two layers join. In this way, the alloyed compound can have fewer natural structural defects than the binary compound, since fewer defects can be transmitted from the substrate to the mercury cadmium telluride crystal. Cadmium zinc telluride is also a relatively soft material, which can be deformed during the normal crystal growth process on Earth. These deformations can introduce undesired changes to the arrangement of cadmium, zinc, and tellurium atoms within the crystal. As such, cadmium zinc telluride is an example of a wider range of similar materials.

By processing cadmium zinc telluride in microgravity, scientists can demonstrate the effects of gravity on the generation of structural defects in the crystal system. From these studies, they should be able to predict the distribution of chemical components within a crystal. This information will be important to the improvement of crystal growth process technology on Earth.

The Study of Dopant Segregation Behavior During the Crystal Growth of GaAs (Gallium Arsenide) in Microgravity

Principal Investigator:
Professor D. H. Matthiesen, Case Western Reserve University, Cleveland, Ohio

Purpose: To investigate techniques for uniformly distributing a dopant, selenium, during the growth of gallium arsenide crystals

Significance: Operating at higher speed and using less power, electronic devices made from gallium arsenide crystals have several theoretical advantages over silicon in computer chips and other semiconductor applications. Gallium arsenide is used in high-speed digital circuits, optoelectronic integrated circuits, solid-state lasers, and a variety of other applications. To produce high-quality gallium arsenide crystals, scientists need to understand the process whereby chemical impurities, either intentionally or unintentionally introduced, are distributed during crystal growth. Doping elements are impurities deliberately added during processing to improve or precisely control the electronic characteristics of a semiconductor crystal. A better understanding of how the dopant selenium is incorporated during crystal growth will help scientists definitively confirm or deny the theories and model used to control crystal growth on Earth. Growing gallium arsenide in microgravity will greatly reduce the gravitational influences that can cause an uneven distribution of dopants in crystals grown on Earth.

Crystal Growth of Selected II-VI Semiconducting Alloys by Directional Solidification

Principal Investigator:
Dr. Sandor Lehoczky, NASA Marshall Space Flight Center

Purpose: To confirm theories of the influence of gravity on the introduction and chemical distribution of structural defects in alloy semiconductors during crystal growth; to grow a crystal of mercury zinc telluride two centimeters long in a low-gravity environment and to determine its chemical and physical properties

Significance: Infrared detectors have many applications in defense, space, medicine, and commercial industry, and mercury zinc telluride has qualities that theoretically make these crystals superior to other infrared detector materials. Mercury zinc telluride alloys are referred to as II-VI alloys because of the positions of the elements in the vertical columns of the periodic table. By varying the amount of the components of this alloy — a process known as *compositional tuning* — the electrical and optical properties can be modified to satisfy the needs of a range of applications. However, the growth of large, single, crystals of mercury zinc telluride that contain a predetermined fraction of each chemical component, is hampered by the complexity of the chemistry involved and the effects of gravity during the growth process. Experiments in microgravity should clarify the role that gravity plays in incorporating the different chemical components into the growing crystal. The composition being grown on this mission has potential applications for infrared detection and imaging systems that can be used for purposes as diverse as petroleum location and management on Earth and the study of distant galaxies and stars.

Vapor Transport Crystal Growth of Mercury Cadmium Telluride in Microgravity

Principal Investigator:
Dr. Heribert Wiedemeier, Rensselaer Polytechnic Institute, Troy, New York

Purpose: To understand the initial phase of the process of vapor crystal growth of complex alloy semiconductors by growing a crystalline layer of mercury cadmium telluride on a cadmium telluride substrate using the vapor transport method; to determine the effects of microgravity on the growth rate, chemical composition, structural characteristics, and other properties of the crystalline layer

Significance: Mercury cadmium telluride crystals have applications as infrared detectors in space, defense, medical, and commercial systems. Detector performance will be greatly improved when scientists are able to grow crystals that are free of structural defects and that have a more uniform distribution of the chemical components. This experiment will grow layers of mercury cadmium telluride on a cadmium telluride substrate to produce a single crystal layer for study. The vapor transport method will cause layers, or thin films, of mercury cadmium telluride to be grown on the substrate in a process called epitaxial layer growth. Better understanding of this crystal growth method will enhance ground-based production of similar semiconductor materials and lead to further improvements in techniques for producing crystals using this process.