HOLOGRAPHY
on the Spacelab 3 mission

By Robert B. Owen and R.L. Kroes

On April 29, the Space Shuttle carried Spacelab 3 into orbit. This can-shaped module is designed to allow laboratory-quality experiments to be conducted in space. The Spacelab 3 mission was primarily devoted to materials science, but experiments were also conducted in life sciences, fluid mechanics, atmospheric science, and astronomy. The Spacelab environment allows research to be done by scientists in the Shuttle, in mission control center, and in the laboratory, all in simultaneous communication.

One of the major experiments conducted on Spacelab 3 was "Solution Growth of Crystals in Zero-Gravity," which was developed by R.B. Lal at Alabama A&M University and R.L. Kroes at NASA Marshall Space Flight Center. In this study, triglycine sulfate (TGS) crystals were produced by a low-temperature solution growth technique. These crystals were grown in the Fluid Experiment System (FES), which is a general purpose facility for studying the behavior of fluids in space. The FES uses holography as its main data gathering system.

This experiment is thus of twofold interest to the optics community. Not only did Spacelab 3 see the first elaborate use of holography in space, but the TGS crystal being studied is a very interesting optical material. In this article, we shall first briefly examine some of the properties of TGS and then outline the optical system of the FES. It will be seen that optics plays an important part in this experiment from beginning to end.

Used as a major data gathering system on Spacelab 3, holography helps to study TGS crystal growth.

The importance of triglycine sulfate

TGS is of interest because of its use as an infrared thermal detector and for basic scientific reasons concerning its ferroelectric properties. It is water soluble, and single crystals can be grown from aqueous solution at moderate temperatures. Since the solution is transparent, the crystallization growth process can readily be studied by optical techniques using light in the visible wavelength region.

Unlike semiconducting photon detectors, which must be cryogenically cooled for efficient operation, TGS works best at or near room temperature and has a very broad spectral response.[1] TGS has this capacity by virtue of being both a ferroelectric and a pyroelectric material that is extremely sensitive to temperature change. It is a ferroelectric with a Curie transition temperature of 49.6°C, and it has a high pyroelectric coefficient and a low dielectric loss factor.

Pyroelectric materials such as TGS form a subgroup of the piezoelectrics and possess a spontaneous electrical polarization below their Curie temperature. The degree of polarization changes with the temperature and can be observed by the generation of an electrical signal when electrodes are placed on opposing sides. The property of ferroelectricity is a subgroup of the pyroelectrics and adds the additional characteristic that the polarization can be reversed by an applied electric field.[2] The Curie temperature is therefore important because above this temperature the ferroelectric properties disappear. Since the Curie temperature for TGS is 49.6°C, the best compromise of desired versus undesired characteristics occurs when TGS is operated at or near room temperature.[1] It has been found recently that some of the properties of TGS (pyroelectric coefficient and figure of merit) can be improved by doping with alanine or growing in a deuterated water solution. TGS possesses a single cleavage plane which occurs perpendicular to its 010 pyroelectric axis, making it desirable for device formation. Unfortunately, the growth on this plane is not very stable and usually produces a multistepped surface.

The importance of TGS for optical applications in astronomy, Earth observation, environmental analysis, and the military is quite evident. However, to date actual performance has not met expectations. Typical TGS crystals have a measured detectivity which is about one order of magnitude below the theoretical limit. It is believed that common crystallographic defects such as inclusions and dislocations adversely affect the detectivity and determine its limits of sensitivity. Some of these defects may be caused by gravity-driven convection.

In Spacelab 3, the mission profile was designed to minimize acceleration while this experiment was being conducted. Thus the growth of the crystal should be diffusion-controlled. By thus eliminating convective effects it is hoped that the experimenters can understand, control and model those aspects of the growth process which lead to high-quality single crystals.

Fluid experiment system optics

The basic FES optical system is holographic. This choice allows optical techniques which might be difficult to apply in orbit to be used in the laboratory by analyzing the holographic reconstructed image after the flight. This approach has already been tested. Holograms have been taken of TGS under microgravity conditions by utilizing a NASA KC-135 aircraft flying as parabolic trajectory.[3]

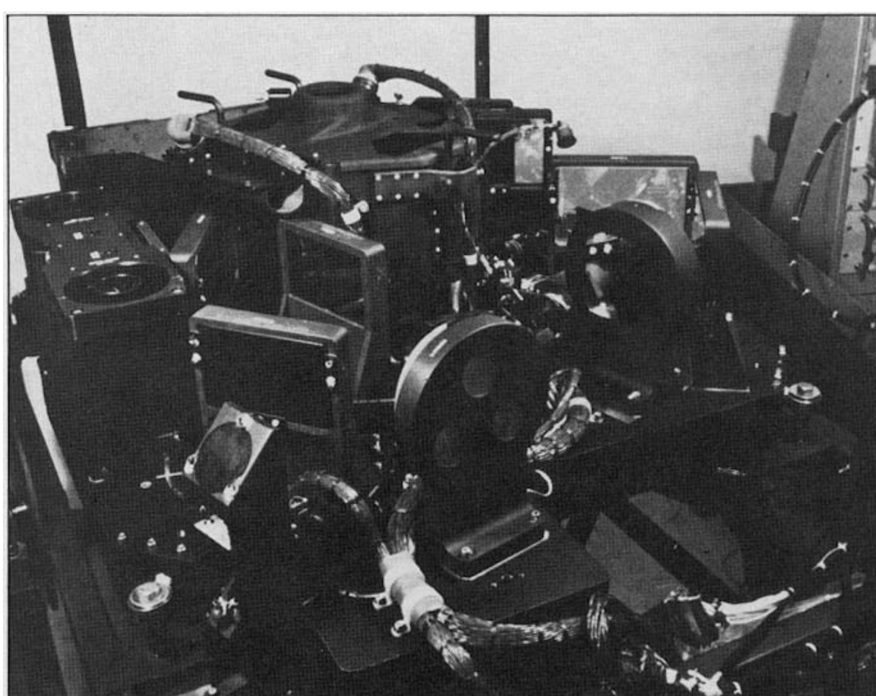
In addition, holograms of TGS have been analyzed in the laboratory using interferometric, schlieren, and shadowgraph techniques. Since there is no facility for processing holograms in Spacelab, it was not possible to examine this optical data during the mission, so the FES optical system included a schlieren system to allow the experimenters to observe the crystal growth in real time.

The optical assembly is mounted on a Newport Corp. optical table. The laser, which is a Spectra-Physics 107A He-Ne with the tube mounts modified to withstand launch, is mounted on the bench back, along with its custom designed power supply. A He-Ne laser was chosen for its reliability, low electrical requirements, and ready availability for use in post-flight holographic reconstruction. The 107A was the largest He-Ne laser that would fit in the space allowed for the system in the standard Spacelab racks.

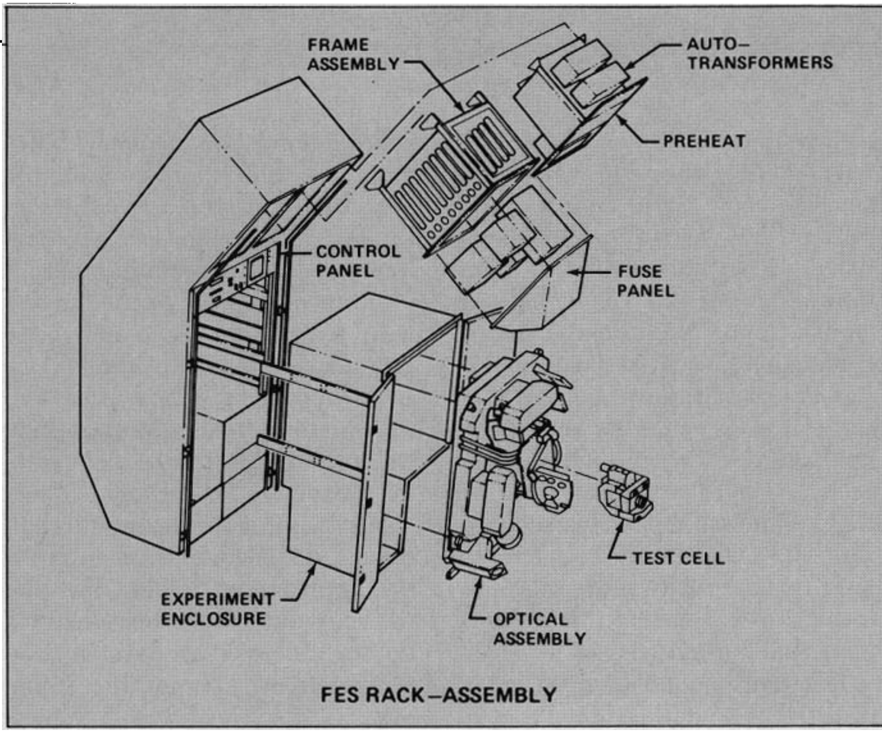
The unexpanded laser beam is directed around the edge of the table and is then expanded to a 6-inch collimated beam. There is no spatial filter since it was felt that there would be problems in pinhole realignment in orbit. The collimated beam is split and deflected by a series of beam splitters and mirrors to form two sideband holographic systems and a schlieren system. The primary holographic system is formed using the beam transmitted directly through the sample chamber as the object beam, and the secondary holographic system is formed using light scattered by the immersed crystal as the object beam.

The reference beam for the transverse system is purposefully reduced to allow for the weak crystal scattering. The primary object beam is split after passing through the test cell, with one arm going to the appropriate holographic film transport and the other going to the real-time schlieren system. The film transport uses flexible 70mm SO-253 film, resulting in typical exposure times of 1/30 second for the primary system and .5 to 1 second for the secondary system. System resolution is 20 μm or better.

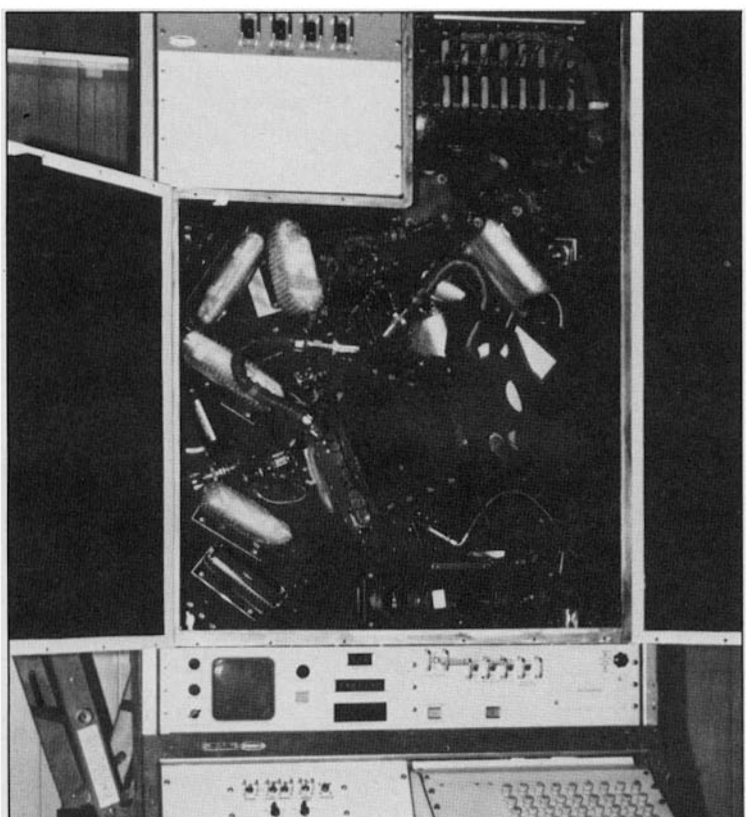
This system permits the recording of both single and double exposure holograms in two separate orthogonal configurations. It is possible to insert a ground glass dif-



FES flight optical system. This photograph shows the actual FES flight holographic schlieren system.



FES rack-assembly. This schematic shows how the FES flight optical system and test cell mount into a standard Spacelab rack. The locations of support electronics and controls are also shown.



FES optics in rack-assembly. The FES optical system is shown mounted in the Spacelab rack. The FES control panel includes a TV screen which allows the schlieren image of the growing TGS crystal to be viewed by the payload specialist during flight. Controls are also available to allow manipulation of the schlieren knife edge.

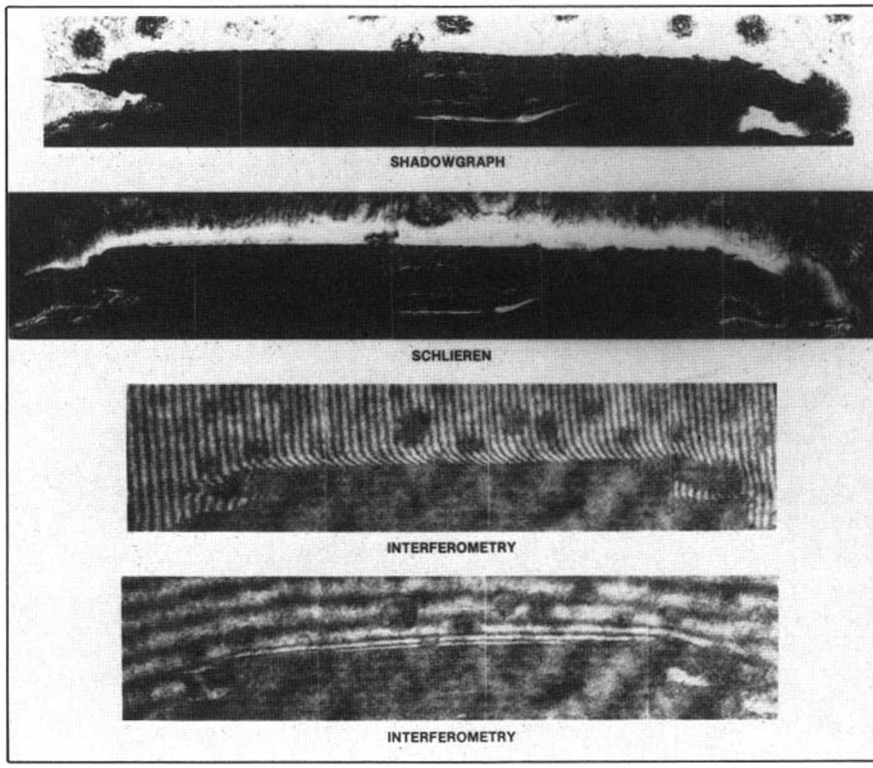
fuser plate to allow diffuse rear illumination transmission holograms to be recorded with the primary camera. The diffuse holograms show three dimensional images of the growing crystal which can be viewed directly by the investigators, while double exposure holograms show a variety of interferometric data on the crystal and on temperature and concentration profiles within the growth solution. The single exposure holograms will be amenable to analysis by schlieren, shadowgraph, interferometric, and microscopic techniques.[4,5] The flight holograms are of excellent quality and are currently being studied by the experiments investigator team.

Additional experiment optical systems

While the prime system of the FES is holographic, it was not possible to use this technique to analyze the experimental process during flight since the holograms were not developed until after the mission. This burden was therefore carried by the FES schlieren optics. The main data which must be known concerns the crystal—is it growing properly? If not, the payload specialist must be able to know what changes to make. It turns out that in spite of the low growth rate of TGS, it is possible to make this determination using a modification of well-known schlieren techniques.

Since light traveling through a non-uniform medium is refracted in the direction of a positive refractive index gradient (usually increasing density), it can be expected that the schlieren image of the crystal growth boundary layer will be affected by growth or dissolution. In the case of a growing crystal, material is being absorbed from solution, the density increases as one moves away from a growing face, and light traveling parallel to that face will be refracted away from the surface. In the case of a dissolving crystal, material is being added to solution, the density increases as one moves towards a dissolving face, and light traveling parallel to that face would be refracted towards the surface. If the crystal is neither growing or dissolving, light traveling parallel to the surface will be only slightly affected.

In a typical schlieren system, this means that a growing crystal would have a light band at the schlieren image of the face towards the knife edge and a dark band on the opposite crystal face. If the crystal is dissolving, the bands will be reversed. If the crystal is neither growing nor dissolving, only minute bands will appear. The entire crystal outline can be examined by this method through rotation of the knife edge. The operation of this technique in microgravity using TGS has been verified by tests on the NASA KC-135 low-gravity simulation aircraft.[6] The FES schlieren optical system was used by the payload specialist to determine whether the test crystal was growing properly during the mission. The flight crystal appeared to grow normally and is currently being analyzed by the investigators.



Results from FES hardware check-out. Test holograms from the FES were used to generate shadowgraph, schlieren, and interferometric images of a growing TGS crystal. All images were made from the same hologram. The main virtue of holography for this experiment is that it allows such techniques to be applied as required in the laboratory after the flight, rather than trying to perform them during the mission. (Holographic reconstruction performed by W. K. Witherow, MSFC)

Ground-based optical systems

In addition to its role during and after the Spacelab 3 mission, optics also played a major part in the laboratory research which built the foundation needed for this experiment prior to flight. In order to mathematically model and accurately control the growth of quality TGS single crystals, it was necessary to determine many of the physical properties of the growth solution. Optical techniques were used extensively in determining the index of refraction as a function of concentration and temperature, the solubility curve, optical dispersion, diffusivity, and other properties.[7]

An Abbe refractometer with a sodium light source was used for index of refraction measurements. Optical dispersion was obtained by applying Cauchy's equation to measurements made on the index of refraction at several different wavelengths. The solubility curve was determined using a shadowgraph technique in which a seed crystal was inserted into a TGS solution and the presence of growth or dissolution determined from the shadowgraph image of the convective plume.

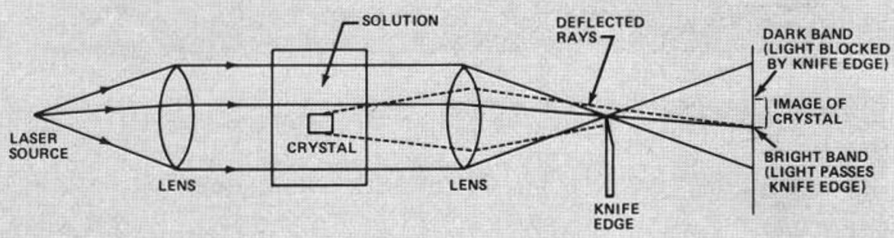
In determining the diffusion coefficient, use was made of the index of refraction as a measure of the concentration changes with time

COVER PHOTOS

A NASA KC-135 low-gravity simulation aircraft was used to test the laser schlieren monitor in microgravity conditions prior to the Spacelab 3 mission. A TGS crystal was examined while both growing and dissolving, and the difference was readily apparent upon inspection of the schlieren image.

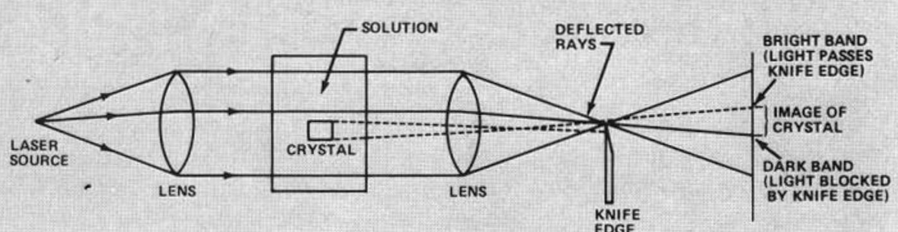
The top photo shows the experimental TGS crystal growing from a seed mounted on the tip of a temperature-controlled sting immersed in TGS solution.

The center photo shows the growth cell for the TGS crystal. It can be seen that gold, which was chosen because of its extreme chemical inertness, is used extensively in this chamber.



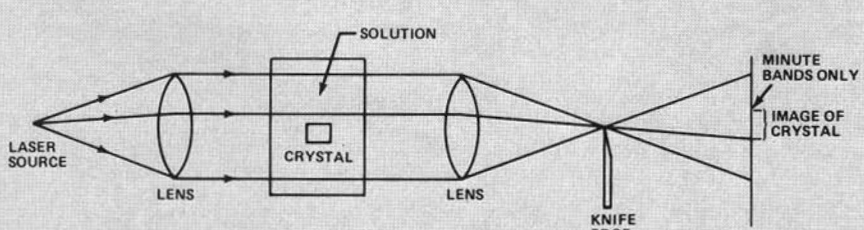
Laser schlieren crystal monitor indicating crystal growth.

As can be seen from the diagram, when the crystal is growing a bright band will appear on the side of the schlieren image which is toward the knife edge. A dark band will appear on the opposite side.



Laser schlieren crystal monitor indicating crystal dissolution.

As can be seen from the diagram, when the crystal is dissolving a dark band will appear on the side of the schlieren image which is toward the knife edge. A bright band will appear on the opposite side.



Laser schlieren crystal monitor indicating transition between growth and dissolution.

As can be seen from the diagram, when the crystal is in transition between growth and dissolution only minute bands will appear on the schlieren crystal image.

along the diffusion path length.[8] Finally, the Raman technique was used to identify the various dissociation species present in the TGS solution and to study its stoichiometry during the diffusion process to verify that the various dissociation products diffuse at essentially the same rate down a concentration gradient.[9] It is thus clear that optics has played a major part in this experiment from the beginning to the end. ◀

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